# INSTRUCTION MANUAL

# MODEL 311

## TRANSISTOR NOISE ANALYZER

For Serial No._____

SCIENTIFIC ATLANTA

Quan-Tech LABORATORIES, INC.

43 SOUTH JEFFERSON ROAD WHIPPANY, NEW JERSEY 07981

~~201-887-5508~~

~~201-361-3100~~

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*ALL SCHEMATICS ARE LOCATED IMMEDIATELY FOLLOWING THE LAST PAGE OF TEXT.*

# CLAIM FOR DAMAGE IN SHIPMENT

The instrument should be tested as soon as it is received. If it fails to operate properly, or is damaged in any way, a claim should be filed with the carrier. A full report of the damage should be obtained by the claim agent, and this report should be forwarded to us. We will then advise you of the disposition to be made of the equipment and arrange for repair or replacement. Include model number and serial number when referring to this instrument for any reason.

# WARRANTY

Quan-Tech Laboratories, Inc. warrants each instrument manufactured by them to be free from defects in material and workmanship. Our liability under this warranty is limited to servicing or adjusting any instrument returned to the factory for that purpose and to replace any defective parts thereof. Electronic tubes and batteries are specifically excluded from any liability. This warranty is effective for one year after delivery to the original purchaser when the instrument is returned, transportation charges prepaid by the original purchaser, and when upon our examination it is disclosed to our satisfaction to be defective. If the fault has been caused by misadjustments, misuse, or abnormal conditions of operation, repairs will be billed at cost. In this case, an estimate will be submitted before the work is started.

Calibration checks of this instrument can easily be made in accordance with the instruction manual. Routine readjustments should never be attempted. If, however, the instrument has been damaged and requires recalibration or alignment, explicit calibration procedures as defined in the instruction manual must be followed.

If any fault develops, the following steps should be taken:

1. Notify us, giving full details of the difficulty, and include the model number and serial number. On receipt of this information, we will give you service data or shipping instructions.

2. On receipt of shipping instructions, forward the instrument prepaid, to the factory. If requested, an estimate of the charges will be made before the work begins provided the instrument is not covered by the warranty.

# SHIPPING

The instruments should be packed in their original containers, or in a strong exterior container and surrounded by two inches of shock absorbing material.

Quan-Tech LABORATORIES

43 SOUTH JEFFERSON ROAD WHIPPANY, NEW JERSEY 07981

201-887-5508

# QUAN-TECH LABORATORIES MODEL 311

## LOW COLLECTOR CURRENT TRANSISTOR NOISE ANALYZER

### GENERAL

The Model 311 was designed specifically for analyzing the noise characteristics of conventional, bipolar transistors operating in the collector current range of from 25 to 1000 microamperes. With some limitations on the operating conditions available, the Model 311 will also measure the noise characteristics of other active, three terminal devices such as the Field Effect Transistor..

Information contained in the standard Quan-Tech Model 310 instruction manual is applicable to the Model 311 with the exception of a few features which will be discussed in the following pages preceding the Model 310 manual.

The significant differences between the Models 310 and 311 are as follows:

1. Collector current ranges. (see SPECIFICATIONS).
2. Model 311 measures transconductance; Model 310 does not.
3. Model 311 measures FET without the additional connections shown on Page 4-4 of the Model 310 manual; Model 310 does not.
4. Model 310 measures current gain; Model 311 does not. All references to the Beta measuring circuitry should be disregarded for the Model 311.

An errata sheet is given following the Model 311 SPECIFICATIONS. This sheet covers the areas of importance for the Model 311 but does not correct all references to the Beta circuitry.

### SPECIFICATIONS

NOISE:

Meter Ranges: 0.01, 0.03, 0.1, 0.3, 1 and 3 microvolts per root cycle, full scale.
1, 3, 10, 30, 100, and 300 picoamperes per root cycle, full scale.

Accuracy: ± 1 db.

Noise Threshold at the collector pin of the test socket is less than:
2 pa/root cycle at 10 Kc.
2 pa/root cycle at 1 Kc.
4 pa/root cycle at 100 cycles.

SPECTRUM ANALYSIS:

Noise measurement made at three frequencies simultaneously; 100 cycles, 1 Kc and 10 Kc. Noise readings are referred to the input of the transistor under test for an equivalent bandwidth of one cycle.

MODEL 311

SPECIFICATIONS (Cont'd)

COLLECTOR VOLTAGE:
Range: ± 0.1 to 30 volts
Meter Ranges: 1, 3, 10, and 30 volts, full scale.
Accuracy: ± 0.1 volt or ± 5% of full scale.

COLLECTOR CURRENT:
Range: 2.5 to 1000 microamperes.
Meter Ranges: 10, 30, 100, 300 and 1000 microamperes, full scale.
Accuracy: ± 5% of full scale.

LEAKAGE CURRENTS ($I_{cbo}$, $I_{ebo}$):
Meter Ranges: 0.03, 0.1, 0.3, 1 and 3 microamperes, full scale.
Accuracy: ± 5% of full scale, ± 5 nanoamperes.

TRANSCONDUCTANCE:
Range: 100 to 40,000 micromhos, metered on one range (measured at 4Kc).

PHYSICAL SPECIFICATIONS:
11"H x 15"W x 11"D.
Weight: 40 pounds

POWER INPUT:
117/234 volts, 60 cps, 30 watts.

E R R A T A

Model 311 Instruction Manual

Section 2, OPERATION:

1. Paragraph 2.b. should read, "Function Switch in NOISE position."
2. Paragraph 4. should read, "Instrument should now be operating and "GM" meter should indicate operating transconductance. The operating range of the AGC amplifier is from 100 to 40,000 micromhos. Noise measurements should not be made if the indicated transconductance is less than 100 micromhos.

Section 3, THEORY OF OPERATION:

1. Third paragraph, first column starting "Beta measurements....." should read, "Transconductance is measured by monitoring the compressor drive current."
2. OPERATIONAL HINTS: INSTRUMENTATION, replace first two paragraphs (all but last) with the following: "The Model 311 will operate satisfactorily for transistors whose transconductance is between 100 and 40,000 micromhos. If the indicated GM is less than 100 micromhos the 4Kc calibrate signal will not be large enough to maintain automatic calibration". NOTE: THE TRANSCONDUCTANCE METER ON THE FRONT PANEL MUST READ 100 MICROMHOS OR GREATER TO OBTAIN CALIBRATED NOISE MEASUREMENTS.
Another calibration error can occur when the transistor is

ERRATA (Cont'd)

Section 3, THEORY OF OPERATION (Cont'd)

2. (Cont'd)
being tested at very low collector current and with resistance in series with the base. If the base circuit capacity represents a significant shunt on the input impedance of the transistor under test at 4Kc. there will be an error in the gain of the system at frequencies other than the calibrate frequency.

Section 4, THEORY AND APPLICATIONS:

1. FIELD EFFECT TRANSISTORS: This section describing Figure 4-9 will continue to apply to both the Model 310 and Model 311. The following will also apply to the Model 311 for serial numbers 200 and above:

Field effect transistors may be checked directly in most cases without the need for the additional material shown in Figure 4-9. The minimum current on any given current range will not in general be zero as it can be with a conventional transistor, but will be determined by the gate to source voltage required for that particular unit. A self-bias limitation exists which, simply stated, means that the current ranges do not necessarily overlap. Proper lead connection for the FET is the following:
Source to emitter, gate to base, and drain to collector.

Section 6, MAINTENANCE AND CALIBRATION:

1. Delete procedure titled COLLECTOR SUPPLY.
2. Under "Current Meter Calibration", paragraphs a. and b. "10 milliamperes" should read 1 milliampere and "10 MA" should read 1 MA.
3. Under "D.C. Voltmeter Calibration", paragraph d. "current range switch to 30" should read "Current range switch to 1000".
4. Under "Compressor Filter", delete paragraph d.; paragraph e, "Maximum voltmeter indication" should read, "Maximum Gm indication".
5. Delete "Base Input Tank Circuit Adjustment", and "Beta Meter Calibration".
6. Add "GM Meter Calibration": For this section a transistor such as a 2N2219 is required. The desirable characteristics are; low leakage, high current gain and low base spreading resistance. These characteristics yield a device whose transconductance is very nearly the reciprical of the emitter-base junction impedance and therefore predictable.

   a. Insert the transistor described above in the test socket.
   b. Set base selector switch to $E_N$, collector current to 1000 microamperes, collector voltage to approximately 5 volts, function switch to NOISE.

ERRATA (Cont'd)

Section 6, MAINTENANCE AND CALIBRATION (Cont'd)

6 (Cont'd)

c. Adjust R1009 for 40 millimhos (full scale deflection of Gm meter).
d. Set collector current to 2.5 microamperes.
e. Adjust mechanical zero of Gm meter for 0.1 millimhos.
f. Repeat d. and e. to eliminate interaction.

7. Under "Noise Meter Calibration" add after "To calibrate, proceed as follows:

a. Set function switch to NOISE position.
b. Insert low level silicon transistor in the test jig and apply 100 microamperes, and 5 volts.

Paragraphs a, b, c, d, e and f should be changed to c, d, e, f, g and h respectively.

8. Under "Threshold Noise Measurement", second paragraph; collector currents of approximately 50 microamperes on the 10 Kc filter... should read "collector currents of approximately 5 microamperes on the 1Kc and 10Kc filters and 20 microamperes on the 100 cycle filter".

9. Under "Threshold Noise Measurement", replace the procedure given for measuring system noise with the following:

"The procedure for measuring system noise under a given operating condition is as follows:

a. Under the operating conditions in question and a transistor in the test socket, note the transconductance reading.
b. Remove the transistor from the test socket.
c. Insert a one megohm resistor in the collector pin of the test socket.
d. Connect an audio oscillator from the one megohm resistor to the ground braid in the test jig cover.
e. Set the oscillator to 4Kc and close the cover interlock switch. (Tune the osc. frequency for maximum Gm meter indication).
f. Set the output level of the oscillator for exactly the Gm meter indication noted in step a.
g. Read system noise on each of the NOISE meters.

# SECTION 1
# GENERAL

The Quan-Tech Model 310 Transistor Noise Analyzer was developed specifically to measure the noise inherent in various transistors. This noise is measured simultaneously at three separate frequencies (100 cycles, 1000 cycles and 10 KC). The low frequency bandpasses are necessary for the measurement of 1/f, or fluctuation noise, whereas the higher frequency bandpass is a measure of "shot" noise, thus providing a three point spectrum analysis of the transistor noise characteristic. To facilitate optimum measurements the system will automatically correct for variations in transistor gain when measuring noise.

The Model 310 can make measurements of the input noise voltage as well as the effective input noise current of a transistor, allowing prediction of noise voltages (or noise figure) for any input impedance. Resistances of 500 and 1000 ohms are provided for making noise figure measurements. In addition to noise, Icbo, Iebo and Beta measurements are easily accomplished with the instrument.

## SPECIFICATIONS

**NOISE RANGE** .....0.01 to 3 microvolts per root cycle, full scale, and 1 to 300 pica-amperes per root cycle, full scale.

**COLLECTOR VOLTAGE** .....0.25 to 30 volts.

**COLLECTOR CURRENT** .....0.3 to 30 milliamperes, full scale.

**LEAKAGE CURRENT** ..... Icbo and Iebo - 0.3 to 30 microamperes, full scale.

**BANDPASS** .....100 CPS, 1000 CPS and 10 KC (Center Frequencies).

**BETA RANGE** .....10 to 300.

**DIMENSIONS** .....11" High, 15" Wide, 11" Deep, overall.

**POWER INPUT** .....117/234 Volts, 60 cycles, 30 watts.

# SECTION 2

# OPERATION

1. For initial operation of the Transistor Noise Analyzer plug the power cord into a suitable source of power. Refer to the plate on the rear of the instrument near the power cord for the voltage and frequency for which this instrument is wired. See Section 6 for instructions on how to change the input voltage. Turn the power switch on. Since there are vacuum tubes contained in the instrument, a few minutes warm-up will be required.

2. Set panel controls as follows:

   a. NPN/PNP selector for proper type.
   b. Function Switch in "$\beta$" position.
   c. Set VOLTS switch and V.ADJ. control for desired transistor collector voltage.
   d. Current switch (MA), to desired current range and I.ADJ. approximately mid-range.
   e. Noise channel attenuators to "3" position.
   f. Base selector switch to $E_N$ position.

3. Insert transistor to be tested and close shield cover which actuates the interlock switch.

4. Instrument should now be operating and "$\beta$" meter should indicate operating Beta.

5. Set I.ADJ. for desired operating current.

6. Turn Function Switch to NOISE position and turn noise channel attenuators until noise meter indication is obtained. This is the shorted input or voltage noise "$E_N$" per $\sqrt{\sim}$ at the filter frequency.

7. To measure the "Noise Figure" of the transistor, set the base selector switch to 1K, measure noise in microvolts and read DB noise figure from the conversion chart (Fig. 2-1). Noise figure for other base resistances may be measured by setting base selector switch to 500 ohms, 10 K ohms ($I_N$) position or EXT position with a suitable resistor attached to the two insulated terminals adjacent to the test transistor socket.

8. Current noise ($I_N$) may be measured directly with the base selector switch set to $I_N$ position, the noise meter reading multiplied by $10^{-10}$ is the noise current in amperes / $\sqrt{\sim}$ at the filter frequency.

9. Leakage currents are measured by setting the function switch to $I_{cbo}$ or $I_{ebo}$ position. The center concentric knob (red dot) indicates the proper microampere full-scale meter range.

NOTE: It may be desirable to reduce the collector voltage when making $I_{ebo}$ measurements.

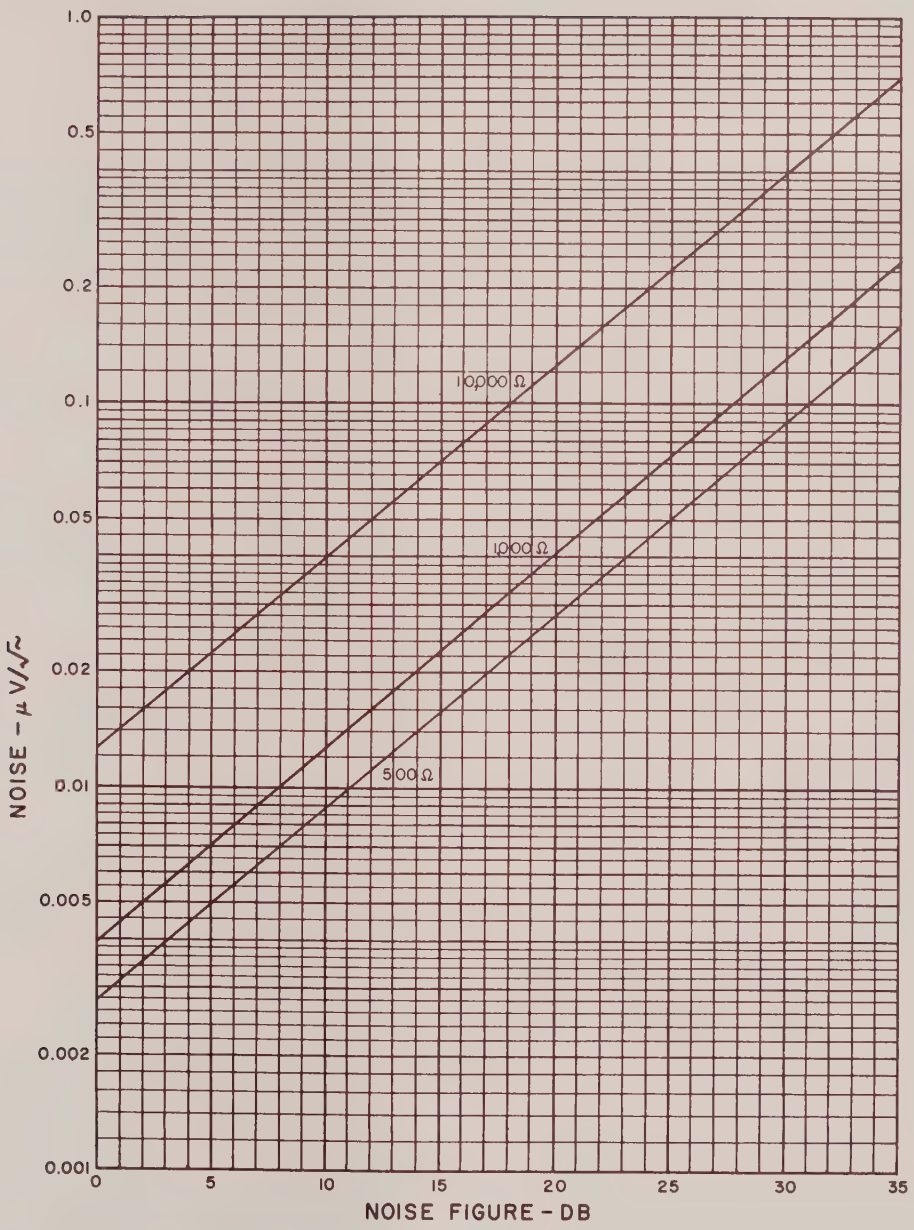



**FIGURE 2-1. TRANSISTOR NOISE FIGURE CONVERSION CHART**

## SECTION 3

# THEORY OF OPERATION

The Model 310 Transistor Noise Analyzer offers three frequencies at which noise measurements can be made simultaneously. The standard frequencies are 100 cycles, 1 KC and 10 KC. There are two basic methods of making a noise measurement. One is the commonly known substitution method in which a noise source is inserted at the input and compared with the internal noise of the device. The other basic method is to have a known amplification factor and a known effective noise bandwidth. It is the latter of the two that is employed in the Model 310.

The bandpass filters are carefully measured and calibrated and the gain of the unit is held at a constant value from the input of the transistor under test to the meter indicators. This gain is controlled by inserting a 4 KC calibrating signal at the base of the test transistor. The output of the transistor is then coupled into Amplifier No. 1 as shown in the detailed block diagram, Fig. 6-1. From there is follows through Compressor No. 1, Amplifier No. 2, Compressor No. 2 and Amplifier No. 3, at which point the 4 KC calibrating signal is removed and fed into the Compressor Amplifier, and compared with a Zener reference to control the two compressors. As a result, the gain at this point is held constant. The noise signals are then fed into filter attenuators and the remainder of the filter amplifier circuitry.

Beta measurements are made by inserting a high impedance in series with the calibrating source and the level of the compressor drive is measured.

Control of the collector-emitter voltage and the collector-current is made by two adjustable regulated power supplies. The measurement of leakage currents are made in the standard fashion.

## OPERATIONAL HINTS

### INSTRUMENTATION

The Model 310 will operate satisfactorily for transistors having a Beta between 10 and 500. Often transistors show a large increase in Beta with increasing collector voltage. If this Beta is in excess of 500 the compressor circuitry fails and erratic behavior is noticeable by large meter fluctuations on the front panel. If Betas of very low values, which often occur at currents below 100 microamperes, are experienced, the compressors operate at their maximum gain and again erroneous readings may result. This may be determined by a further decrease in current and noting if the noise measurement increases proportionately. Another error may be seen at high frequencies if low frequency transistors are being measured. This usually is due to either capacitance between the base-emitter junction or a large decrease in the Beta over and above what it is at the 4 KC calibrating frequency.

It should be pointed out that during Beta calibration the impedance of the calibrating source is approximately 150,000 ohms and that an error in the Beta measurement will be experienced for transistors having input impedances approaching this value.

There are five input positions available: The $E_N$ position, the 500 and 1000 ohm positions, the $I_N$ position and an external source impedance position. If an external source impedance is inserted be sure that the DC drop across this impedance does not exceed 1 volt due to base drive. If this voltage is exceeded the collector power supply may lose regulation. It is often convenient when working with relatively low currents to use an external resistor of 100,000 ohms for measuring the current noise. In this case a correction factor of 10 to 1 should be applied to the meter readings. In making current measurements with the 10,000 ohm, $I_N$, position, a limit of $1.3 \times 10^{-12}$ amperes is caused by the thermal noise in the 10 K resistor. If transistors indicate a noise level near this value, a correction for the resistor noise must be made. See Figure 3-1.

### TRANSISTORS

The basic transistor noise theory is explained in Section No. 4. However, there are a few applications of this theory which would be helpful to the user.

The shot and thermal noise are straightforward and can be readily calculated. However, the excess noise and avalanche noise effects vary radically with the type of transistors being tested. Defects in transistors which cause large current densities may be easily measured and will show up as excess noise for the given type of transistor. For instance, a fractured or partially fractured base junction will show a large noise voltage $E_N$. Contamination of the surface or an avalanche condition will show a large value of $I_N$. Both of these noise generators will usually have 1/f noise far in excess of the normal amount.

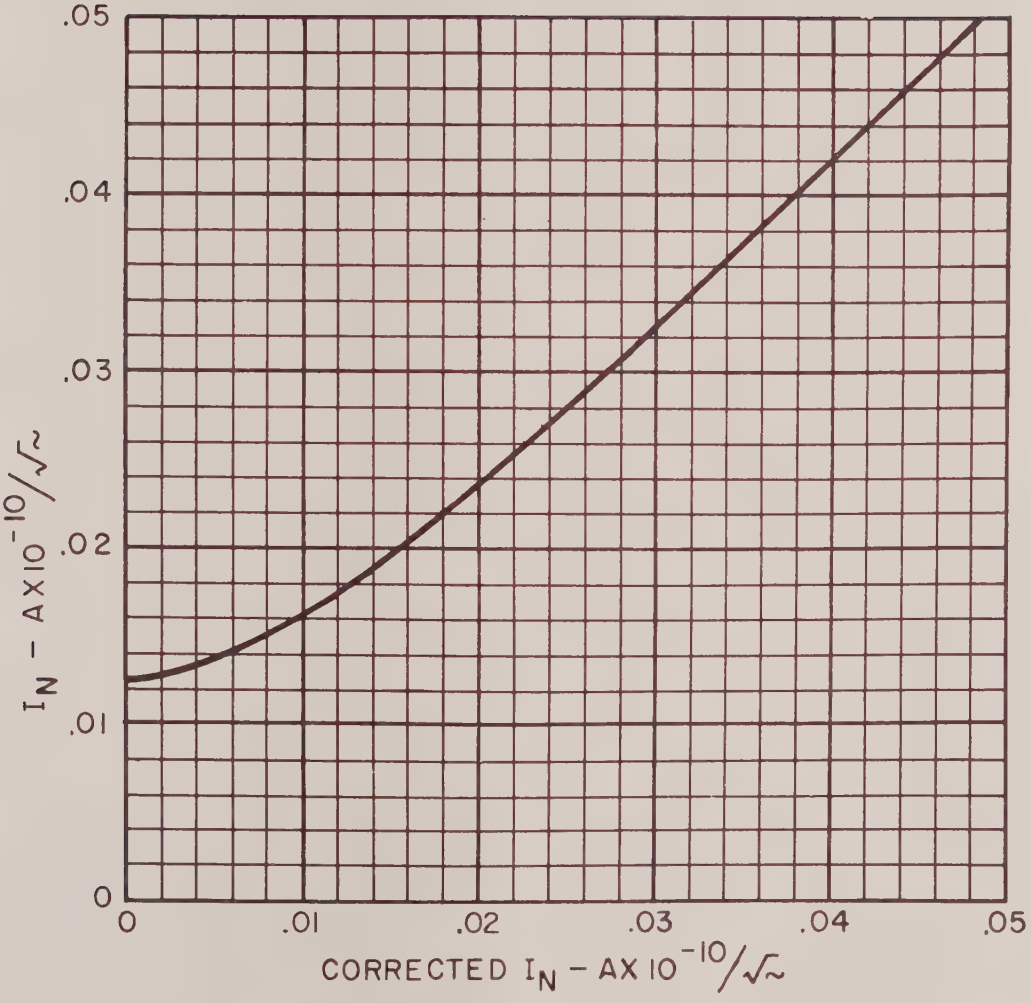



FIGURE 3-1. CORRECTION FOR LOW VALUE OF $I_N$

SECTION 4

# THEORY AND APPLICATIONS OF TRANSISTOR NOISE

An analysis of the internal noise sources of a transistor may be made by referring to Figure 4-1.

## SHOT AND THERMAL NOISE

The currents shown are independent of each other and each shows full shot noise. Therefore, the noise currents generated through these paths may be found from the Schottky equation.

$$\overline{I_s^2}^{\frac{1}{2}} = (2 \epsilon I_{DC} \Delta F)^{\frac{1}{2}}$$

Consider a collector current of 1 ma and a bandwidth of 1 cycle, then:

$$\overline{I_{sc}^2}^{\frac{1}{2}} = (2 \times 1.59 \times 10^{-19} \times 10^{-3} \times 1)^{\frac{1}{2}}$$
$$= 1.79 \times 10^{-11} \text{ amps} / \sqrt{\sim}$$

Although $\overline{I_{sc}^2}^{\frac{1}{2}}$ passes through both the base-emitter and base-collector junctions it shows complete correlation and may be considered as effectively through the base-emitter impedance ($R_e$) only. The resultant noise voltage due to the collector current shot noise in this case is:

$$\overline{E_{sc}^2}^{\frac{1}{2}} = \overline{I_{sc}}^{\frac{1}{2}} R_e$$

$$\text{Where } R_e = \frac{k T}{\epsilon I_e} = \frac{k T}{\epsilon (I_c + I_b)}$$
$$\cong \frac{25 \times 10^{-3}}{I_e}$$

and for 1 ma. $R_e \cong 25$ ohms.

$$\text{Thus } \overline{E_{sc}^2}^{\frac{1}{2}} = 1.79 \times 10^{-11} \times 25 =$$
$$0.44 \times 10^{-9} \text{ volts} / \sqrt{\sim}$$

$r_{b'b}$, the base spreading resistance contributes thermal noise and may be calculated from Nyquist's equation

$$\overline{E_t^2}^{\frac{1}{2}} = (4 k T R \Delta F)^{\frac{1}{2}}$$

and for a 100 ohm $r_{b'b}$

$$\overline{E_t^2}^{\frac{1}{2}} = 1.26 \times 10^{-9} \text{ volts} / \sqrt{\sim}$$

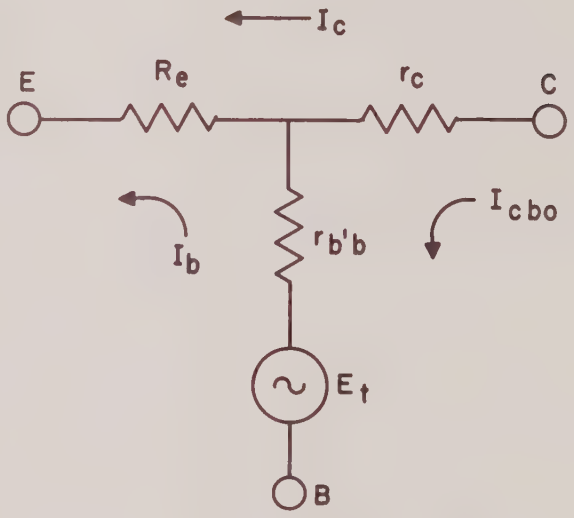



**FIGURE 4-1. EQUIVALENT SHOT AND THERMAL NOISE GENERATORS**

Both $\overline{E_{sc}^2}^{\frac{1}{2}}$ and $\overline{E_t^2}^{\frac{1}{2}}$ are major noise sources in the transistor even with a zero impedance source generator. $\overline{E_{sc}^2}^{\frac{1}{2}}$ and $\overline{E_t^2}^{\frac{1}{2}}$ may thus be added in an rms fashion and be considered as a noise voltage generator ($E_N$) in series with the base as shown in Figure 4-2. Although the d-c currents $I_b$ and $I_{cbo}$ develop shot noise currents through $r_{b'} + R_e$ and $r_{b'}$ respectively, they may be neglected unless very low values of $\beta$ and $I_e$ are considered.

When large input impedances are considered the noise currents resulting from $I_{cbo}$ and $I_b$ are the major contributors. Thus $\overline{I_{sb}^2}^{\frac{1}{2}} = (2 \epsilon (I_b + I_{cbo}) \Delta F)^{\frac{1}{2}}$.

If $I_{cbo} = 1 \times 10^{-6}$ amperes and assuming a $\beta$ of 100 with an $I_e$ of $1 \times 10^{-3}$ amperes.

$$\text{Then } \overline{I_{sb}^2}^{\frac{1}{2}} =$$
$$[2 \times 1.59 \times 10^{-19} (10 \times 10^{-6} + 1 \times 10^{-6}) 1]^{\frac{1}{2}}$$
$$= 1.87 \times 10^{-12} \text{a} / \sqrt{\sim}$$

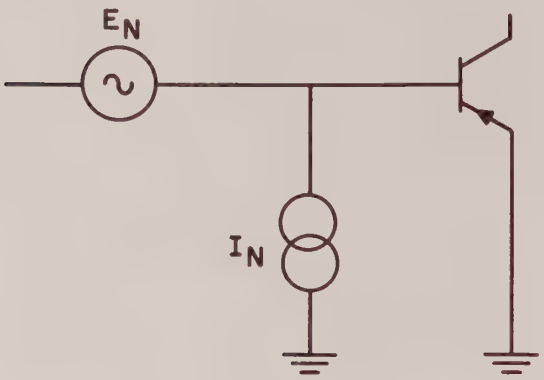



**FIGURE 4-2. EQUIVALENT NOISE GENERATORS**

The current $\overline{I_{sb}^2}^{1/2}$ may be considered as the equivalent noise current generator, $I_N$, as shown in Fig. 4-2.

An optimum input impedance occurs when both $I_N$ and $E_N$ contribute equally to the noise thus:

$$R_o = \frac{E_N}{I_N}$$

and for the idealized transistor considered,

$$R_o = \frac{(.44^2 + 1.26^2)^{1/2} \times 10^{-9}}{1.87 \times 10^{-12}} = \frac{1.34 \times 10^{-9}}{1.87 \times 10^{-12}} = 720 \text{ ohms.}$$

There are second order corrections which have been omitted in the above theory of shot and thermal noise in transistors.

For a more thorough treatment of the subject, reference should be made to "Fluctuation Phenomena in Semi-conductors" by A. van der Ziel.

### EXCESS (1/f) AND AVALANCHE NOISE

In addition to the shot and thermal noise sources there are excess noise and avalanche noise mechanisms. The exact cause of the excess noise is not clearly understood. However, it can be expressed by the following equation:

$$\overline{I_{ex}^2}^{1/2} = (C\, I^a\, F^\gamma)^{1/2}$$

The exponent $a$ is very close to 2 and the value of $\gamma$ is about $-1.09$. Little error is involved if the excess noise current is assumed to be proportional to the d.c. current and to have a 1/f power spectrum. The constant C is determined experimentally since it is a function of material and shape factor.

It is difficult to predict the magnitude of the excess noise in a transistor. $I_c$, $I_b$ and $I_{cbo}$ all contribute. However, their relative magnitudes are dependent upon the type of transistor structure and its operating conditions.

The above noise mechanisms (thermal, shot, and excess) all have a Gaussian amplitude distribution which is well defined mathematically. Avalanche noise on the other hand may have amplitude and frequency distributions that are difficult to define. Noise of this type is generated by the avalanche or multiplication phenomena between collector and base, and often increases exponentially with increasing collector voltage.

### TABLE OF SYMBOLS

- B = Transistor base terminal
- C = Transistor collector terminal
- E = Transistor emitter terminal
- $E_{sc}$ = Shot noise voltage due to $I_c$
- $E_t$ = Thermal noise voltage due to $r_{b'}$
- $I_{ex}$ = Excess noise current
- $I_s$ = Shot noise current
- $I_{sb}$ = Shot noise current due to $I_b$ and $I_{cbo}$
- $I_{sc}$ = Shot noise current due to $I_c$
- $\epsilon$ = Charge on electron, $1.59 \times 10^{-19}$ coloumbs.
- k = Boltzman's constant. $1.38 \times 10^{-23}$ joules / °C
- T = Temperature in degrees Kelvin
- $R_o$ = Optimum source resistance

### ANALYSIS TECHNIQUES

The Quan-Tech Models 310 and 311[1] Transistor Noise Analyzers, far beyond mere total noise measurements, can provide a substantial amount of detailed information regarding the internal condition of a transistor, indicating not only the region in the device where a fault exists, but also in many instances the specific nature of the defect.

In addition, proper interpretation of the results of noise measurement provides a truly sound basis for establishing "approved vendor" lists and incoming-inspection standards from the standpoint of the most realistic yardstick for "quality" currently available.

To understand best the noise characteristic of a transistor, it is advisable to begin by determining the level of noise that would be generated were the transistor an "ideal" one (i.e., one generating thermal and shot noise only, with no 1/f or avalanche[2] noise present).

[1]The Models 310 and 311 are essentially similar, except that the Model 311 is intended primarily for operation at low values of collector current. It should be noted that as long as the test transistor is operated within the collector-current range of the instrument, system sensitivity is adequate to measure down to theoretical minimum noise values. The sensitivity of these instruments cannot be tested without a transistor in the test jig. See Section 6 for detailed information on making system sensitivity test.

[2]See, "Electrical Noise and Component Reliability," published by Quan-Tech Laboratories, Inc., for a general discussion of various types of electrical noise.

Noise current and noise voltage in this "ideal" transistor may be readily found from the following expressions and the accompanying graphs:

Ideal Noise Voltage $E_n = (E^2 \text{ thermal} + E^2 \text{ shot})^{\frac{1}{2}}$

Ideal Noise Current $I_n = (2q [I_b + I_{cbo}])^{\frac{1}{2}}$

Thermal and shot noise voltages originate respectively from the base spreading resistance and from the base-emitter junction (due to emitter current). They may be determined for the given operating conditions from the graphs in Figure 4-3 and Figure 4-4 respectively. Shot noise current may be determined from Figure 4-5.

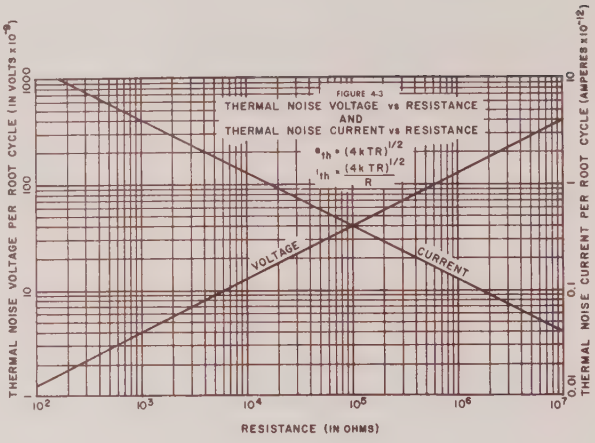
These "ideal" noise current and voltage values represent the theoretical minimum of noise the device could exhibit for the given operating condition. However, no transistor will operate at this minimum value. Depending on the individual transistor, 1/f noise will be present, and it is possible that avalanche noise, too, may contribute to the total noise. Measurement with the Quan-Tech Model 310 or 311 will reveal the extent to which the device deviates from the "ideal."

1/f noise, dependent upon current density within the device, is of inestimable value in revealing defects in the transistor.

a) *Base-emitter region* — Such faults as defective contacts, fractures or irregularities in the junction may be readily detected by measuring noise voltage ($E_n$) with the transistor operated under high-current conditions. (NOTE: Care should be taken to see that the total dissipation rating of the transistor is not exceeded during this test. Frequently, it is necessary to reduce the applied voltage before increasing the current to protect the transistor from damage.) These conditions are indicated by an abnormally high level of 1/f noise. It should be noted that what constitutes a "normal" level of 1/f noise varies from transistor type to transistor type. It is to be expected, for example, that devices of small cross section, such as mesa transistors, generally have a substantially higher 1/f noise level than do larger types. The norm for a given type under a given operation condition may be readily determined by making and comparing measurements of a number of units.

b) *Base region* — Defects in the base region similar to those in the base-emitter region may be detected by measuring the 1/f noise current ($I_n$) at lower value of applied current than for the base-emitter test.

c) *Collector-base region* — Surface contamination may be detected by testing for 1/f noise current ($I_n$) at very low collector current (a few hundred microamperes) and gradually increasing the collector voltage. If the noise current increases approximately proportionately with voltage, surface contamination is most probably present, and is acting as a semiconductor-resistor across the collector-base junction. If



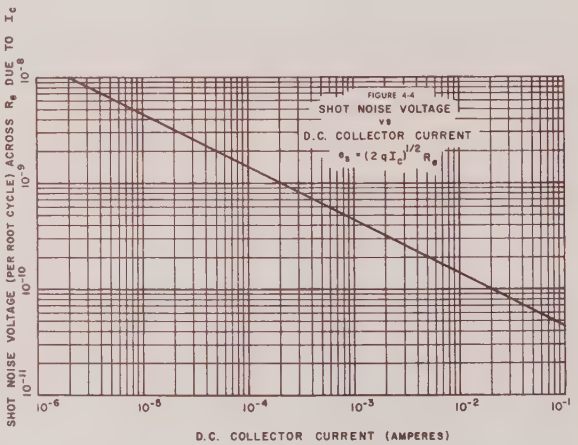
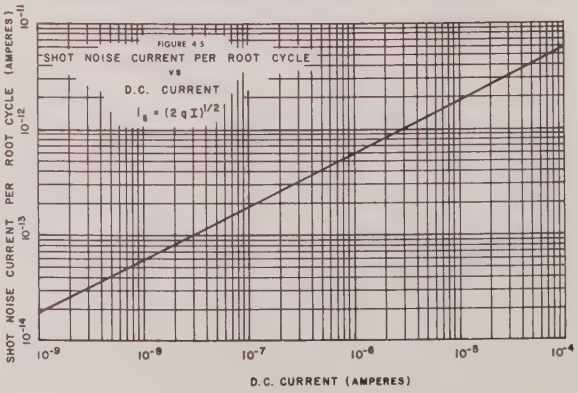



FIGURE 4-4
SHOT NOISE VOLTAGE
vs
D.C. COLLECTOR CURRENT
$e_s = (2qI_c)^{1/2} R_e$
SHOT NOISE VOLTAGE (PER ROOT CYCLE) ACROSS $R_e$ DUE TO $I_c$
D.C. COLLECTOR CURRENT (AMPERES)



the noise increases abruptly, or essentially exponentially with the voltage, the collector-base junction is breaking into avalanche. It should be noted that *any* transistor will avalanche eventually as the voltage is increased. It is when the avalanche takes place *within rated operating voltages* that trouble is indicated, probably in the form of an irregularity of the collector-base junction.

d) *"Sleepers"* — This term has been applied to a particular type of transistor defect that is characterized by the fact that on immediate examination no excessive noise problem is evident. However, as the test is prolonged up to a period of many hours, the noise level rises. Generally, if the test current or voltage is interrupted, the transistor returns to its state of quiet operation. However, as the test progresses once more, the transistor will again increase in noise output. To detect the "sleeper", tests of as long as 24 hours or more may be required. Fortunately, in the practical case, "sleepers" are quite rare, and once a reliable vendor is found, this problem may generally be negelected.

### Vendor Selection

Even limited experience with transistor noise analysis will reveal that the differences in noise characteristic between transistors of the same type from different manufacturers varies very broadly. A significant evaluation of quality of a given transistor type may be made by testing a batch for noise, and plotting the results in the form of distribution graphs as shown in Figures 4-6, 4-7 and 4-8. All three of these graphs were drawn for the same type of transistor — a medium frequency germanium device. Figure 4-8 shows an excessively broad spread, indicating a serious lack of production control on the part of the manufacturer. Such a spread would eliminate this supplier from the "approved vendor" list. Figure 4-7 shows a substantially better spread, but still the grouping is more than one might desire. Figure 4-6 shows an excellent pattern, with all units closely grouped around a low noise level. This graph shows excellent process control and justifies placing the manufacturer on an "approved vendor" list for transistors of this type.

It should be noted that vendor selection of this type will not obviate the necessity for checking transistors at incoming inspection for noise, but it will go a long way toward reducing the number of rejects at this inspection point, and thus substantially reduce the real cost of the transistor to the user.

### Production Testing

The extent to which individual transistors should be inspected for noise depends upon the degree of re-

FIGURE 4-6

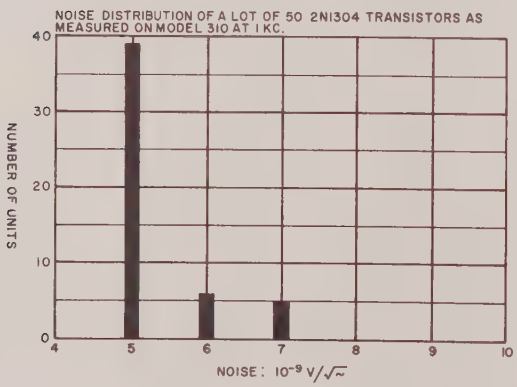



FIGURE 4-7

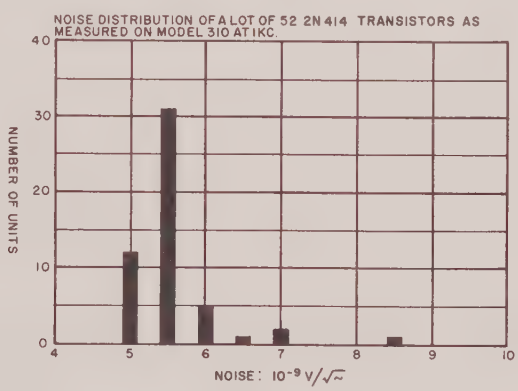
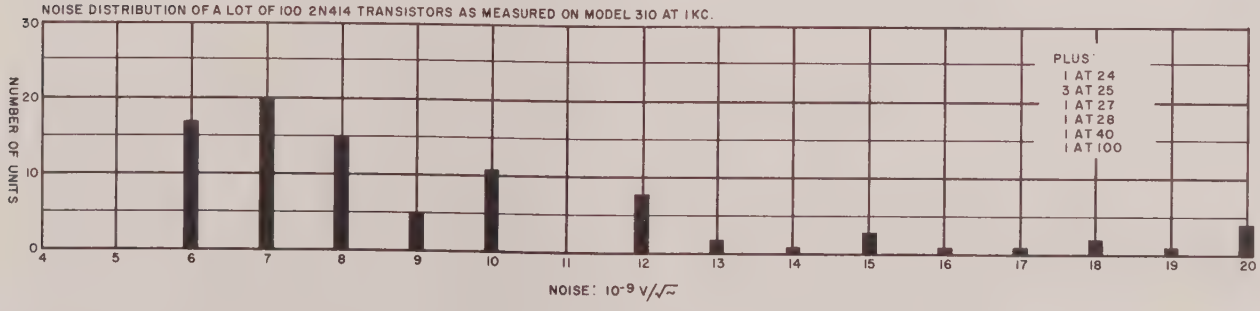



FIGURE 4-8



liability required of the equipment in which they are to be used.

In many circumstances where *extreme* reliability is not required, a single noise measurement per transistor usually suffices. The common practice is to measure noise voltage with the transistor operated under conditions of the highest voltage possible within the ratings of the transistor, and at a collector current value comparable to that of the actual circuit. With the resistance selector at 1000 ohms, noise figure measurements may be readily made.

For maximum reliability, it is advisable to measure both noise current ($I_n$) and noise voltage ($E_n$) under conditions of low collector current and high voltage as well as high collector current and low voltage. In this way, a detailed analysis of each transistor may be made.

**Field-Effect Transistors**

The Models 310 and 311 may be used for either laboratory or production testing of field-effect transistors by following the steps outlined below:

1. Set base resistance switch to EXT position.
2. Turn current control fully CCW.
3. Ground emitter terminal (E) in test jig to shield strap.
4. Remove shorting bar between terminals.
5. Rewire terminals in test jig as shown in Figure 4-9.

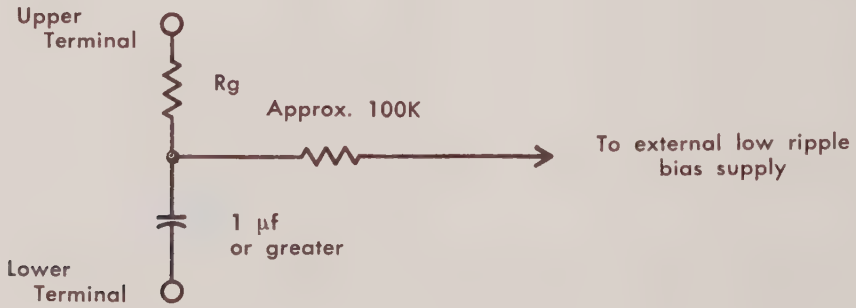
The Models 310 and 311 will measure noise in any field-effect transistor within the limits outlined in Section 3. The AGC circuit of the instruments will function over the following ranges of $G_m$:

| | $G_m$ Range |
|---|---|
| Model 310 — | 1000 μmhos to 100,000 μmhos |
| Model 311 — | 100 μmhos to 40,000 μmhos |

**Additional Applications Information**

The fullest capabilities of the Models 310 and 311 may well not be appreciated by the user who is not familiar with the equipment. Every effort has been made by Quan-Tech Laboratories to make both the Instruction Manual and associated applications notes as complete as possible, but since it is impossible to anticipate all of the questions that might arise, Quan-Tech's Engineering Department will provide detailed, individual advice and instructions on the capabilities and functions of the equipment.

If you should have any additional questions concerning the use or operation of the Models 310 or 311, address your inquiry to the Engineering Department, giving as many particulars as possible. Information may also be obtained by telephone, and all inquiries will receive prompt and complete attention.




NOTE: Exact circuit values are not critical, but should be of the general magnitude shown.

**FIGURE 4-9 MODIFICATION OF TEST JIG FOR FIELD EFFECT TRANSISTORS**

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43 South Jefferson Road
Whippany, N. J.
201-887-5508

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# A DISCUSSION OF ERRORS DUE TO BANDWIDTH WHEN MAKING SPOT NOISE MEASUREMENTS

Considerable confusion occasionally arises over the effect that bandwidth has on the accuracy of spot noise measurements which, by definition, refer to an equivalent noise bandwidth of one Hz. Practically all noise analyzers use an equivalent noise bandwidth much greater than one Hz and effectively divide the actual noise voltage by the square root of the bandwidth to obtain spot noise or noise spectral density. If the noise being measured is white (amplitude constant with frequency) there is no problem in accepting the above philosophy, however, most semiconductors generate considerable amounts of 1/f noise which has an amplitude characteristic inversely proportional to the square root of the frequency. The question arises as to how much error is introduced in a given bandwidth if 1/f noise is present. Some transistor specifications have even gone so far as to specify the bandwidth (200 Hz for 1 KHz spot noise figure) in an attempt to minimize the error. The following analysis has been made to show that bandwidth, within reason, contributes basically no error regardless of whether white or 1/f noise is present.

Spot noise measurements (equivalent noise bandwidth of one Hz.) taken on a Quan-Tech Laboratories Model 310 are actually made with filter bandwidths of typically 300 Hz and 900 Hz for the 1 KHz and 10 KHz channels respectively. The error in the noise measurement introduced by measuring over these particular bandwidths instead of one Hz bandwidth is as follows:

Conversion factors for white noise:

$$E_{\text{total in 300 Hz BW}} = E_{1\text{KHz}} \ (300)^{1/2} = E_{1\text{KHz}} \ (17.32)$$

$$E_{\text{total in 900 Hz BW}} = E_{10\text{KHz}} \ (900)^{1/2} = E_{10\text{KHz}} \ (30)$$

Conversion factors for 1/f noise

$$E_{\text{total in 300 Hz BW}} = E_{1\text{KHz}} \ (1\text{KHz})^{1/2} \ \left(\ln \frac{f_2}{f_1}\right)^{1/2}$$

$$= E_{1\text{KHz}} \ (31.6) \ \left(2.3 \log \frac{1160}{860}\right)^{1/2}$$

$$= E_{1\text{KHz}} \ (17.30)$$

$$E_{\text{total in 900 Hz BW}} = E_{10\text{KHz}} \ (10\text{KHz})^{1/2} \ \left(\ln \frac{f_2}{f_1}\right)^{1/2}$$

$$= E_{10\text{KHz}} \ (10^2) \ \left(2.3 \log \frac{10460}{9560}\right)^{1/2}$$

$$= E_{10\text{KHz}} \ (29.9)$$

It can be seen from the above that the error resulting from using the white noise conversion factor when the noise is actually 1/f is essentially zero. Even bandwidths as wide as 1KHz geometrically centered around 1 KHz contribute negligible error compared to the other errors usually associated with the measurement of random noise.

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# 1 KHz SPOT NOISE FIGURE VS BROADBAND NOISE FIGURE [1]

The following is an analysis of the difference to be expected between noise figure measurements made by these two presently accepted standards.

The 1 KHz spot noise figure is measured at 1 KHz with the bandwidth of the detector small as compared to 1 KHz. Both the thermal noise of the source and the white, as well as 1/f noise contributed by the device under test are measured at 1 KHz only.

In the broadband case, the noise figure is measured over a bandwidth extending from 10 Hz to 10,000 Hz. This bandpass is specified to be 3db down at 10 and 10,000 Hz, and to have a 6db/oct roll-off. The broadband noise figure is a measure of the white and 1/f noise generated within this bandpass, including the skirts.

Table No. 1 lists the noise figure for both the broadband and 1 KHz spot methods, assuming all white noise to be generated by the source resistance, and all noise generated by the device, to be 1/f. This results in the maximum deviation between the two methods. If the device under test contributes white noise (thermal and shot) as well as 1/f noise, the difference will be less.

TABLE NO. 1

| 1 KHz spot noise figure in db | Broadband noise figure in db | △N.F. in db |
|---|---|---|
| 0.5 | 0.20 | 0.30 |
| 1.0 | 0.42 | 0.58 |
| 2.0 | 1.00 | 1.00 |
| 3.0 | 1.58 | 1.42 |
| 5.0 | 2.90 | 2.10 |
| 7.0 | 4.40 | 2.60 |
| 10.0 | 6.95 | 3.05 |
| 20.0 | 16.42 | 3.58 |

The noise voltage contained within a bandpass may be expressed as:

$$\overline{E^2}^{1/2} = \left[\int_0^\infty E^2(F)\,G^2(F)\,df\right]^{1/2} \qquad \text{EQUATION 1}$$

or the voltage squared:

$$\overline{E^2} = \int_0^\infty E^2(F)\,G^2(F)\,df \qquad \text{EQUATION 2}$$

where $E^2(F)$ describes the noisepower spectrum and $G^2(F)$ describes the power gain of the circuit.

Since the broadband measurement contains a low pass and a high pass filter, the gain function is:

$$G_{LP}(F) = \frac{1}{\left(1 + \frac{f^2}{f_2^2}\right)^{1/2}} \qquad \text{EQUATION 3}$$

$$G^2_{LP}(F) = \frac{f_2^2}{f_2^2 + f^2} \qquad \text{EQUATION 4}$$

$$G_{HP}(F) = \frac{1}{\left(1 + \frac{f_1^2}{f^2}\right)^{1/2}}$$ EQUATION 5

$$G_{HP}^2(F) = \frac{f^2}{f_1^2 + f^2}$$ EQUATION 6

where $f_2$ and $f_1$ are the upper and lower cutoff frequencies.

Thus the magnitude of the white noise contained in the broadband measurement where $E^2(f)$ is a constant for all frequencies and is assigned unit magnitude is given by:

$$\overline{E_W^2} = \int_0^\infty G_{LP}^2(F)\, G_{HP}^2(F)\, df$$ EQUATION 7

$$\overline{E_W^2} = \int_0^\infty \left(\frac{f^2}{f_1^2 + f^2}\right)\left(\frac{f_2^2}{f_2^2 + f^2}\right) df$$ EQUATION 8

By partial fraction expansion we have:

$$\overline{E_W^2} = \int_0^\infty \left[\frac{\frac{1}{(f_2^2 - f_1^2)}}{f_1^2 + f^2} + \frac{\frac{1}{(f_1^2 - f_2^2)}}{f_2^2 + f^2}\right] f_2^2\, f^2\, df$$ EQUATION 9

$$\overline{E_W^2} = \frac{f_2^2}{f_2^2 - f_1^2}\left(f - f_1 \tan^{-1}\frac{f}{f_1}\right) + \frac{f_2^2}{f_1^2 - f_2^2}\left(f - f_2 \tan^{-1}\frac{f}{f_2}\right)\Bigg|_0^\infty$$ EQUATION 10

$$\overline{E_W^2} = \frac{f_2^2}{f_2^2 - f_1^2}(f_2 - f_1)\frac{\pi}{2} = \frac{f_2^2}{f_2 + f_1}\frac{\pi}{2}$$ EQUATION 11

$f_1$ = 10 Hz and $f_2$ = 10,000 Hz
Therefore:

$$\overline{E_W^2} = 15.7 \times 10^3 \text{ VOLTS}^2$$ EQUATION 12

The derivation of the magnitude of 1/f noise is similar to the above for white noise. Prior to integration, equation 9 should be multiplied by 1/f, since in this case the function $E^2(F) = 1/f$.

$$\overline{E_{1/f}^2} = \int_0^\infty \left[\frac{\frac{1}{(f_2^2 - f_1^2)}}{f_1^2 + f^2} + \frac{\frac{1}{(f_1^2 - f_2^2)}}{f_2^2 + f^2}\right] f_2^2\, f\, df$$ EQUATION 13

$$\overline{E^2_{1/f}} = \frac{1}{2}\,\frac{f_2^2}{f_2^2 - f_1^2}\,(\ln f^2 + f_1^2 - \ln f^2 + f_2^2)\Big|_0^\infty$$

EQUATION 14

$$\overline{E^2_{1/f}} = \frac{1}{2}\,\frac{f_2^2}{f_2^2 - f_1^2}\,\ln\,\frac{f^2 + f_1^2}{f^2 + f_2^2}\Big|_0^\infty$$

EQUATION 15

$$\overline{E^2_{1/f}} = \frac{f_2^2}{f_2^2 - f_1^2}\,\ln\,\frac{f_2}{f_1}$$

EQUATION 16

Again f = 10 Hz and $f_2$ = 10,000 Hz and

$$\overline{E^2_{1/f}} = 6.9\ \text{VOLTS}^2\ \text{(unit spectral density at 1 Hz)}$$

EQUATION 17

The above solution is based on unit spectral density for the 1/f noise at 1 Hz. For comparison the 1/f noise should be set equal to the white noise at 1 KHz. Thus a multiplier of 1000 is required and:

$$\overline{E^2_{1/f}} = 6.9 \times 10^3\ \text{VOLTS}^2\ \text{(unit spectral density at 1 KHz)}$$

EQUATION 18

$$\frac{\overline{E^2_{1/f}}}{E_W^2} = \frac{6.9 \times 10^3}{15.7 \times 10^3} = .44 \text{ or } -3.58\,\text{db}$$

EQUATION 19

Table No. 1 is derived from equations 20 and 21.

$$\text{1 KHz SPOT N.F.} = \frac{4kTRg + E^2_{1/f}}{4kTRg}$$

EQUATION 20

$$\text{BROADBAND N.F.} = \frac{4kTRg(15.7 \times 10^3) + E^2_{1/f}\,(6.9 \times 10^3)}{4kTRg(15.7 \times 10^3)}$$

EQUATION 21

where Rg - generator or source resistance and $E^2_{1/f}$ = 1/f noise spectral density at 1 KHz.

(1) Prepared by Quan-Tech Laboratories, Inc. 43 South Jefferson Road, Whippany, N. J.

# SECTION 5

# CIRCUIT DESCRIPTION

## POWER SUPPLIES

Power is supplied to the instrument via line plug P101, fuse F101, front panel power switch S101 and the primary of the main power transformer T101.

### 26 V General Supply

The 26V General Supply furnishes power for the vacuum tube voltmeter heaters and all the noise measuring circuits with the exception of the transistor under test. Conventional regulated power supply design is used; its operation is briefly as follows:

Unregulated DC is supplied by secondary #1 of T101, bridge rectifier CR301, 302, 303, 304 and capacitor C301. A ½-amp. fuse F301 is incorporated to prevent damage to the pass transistor Q304 in case of accidental short circuit or overload. Control for the pass transistor is obtained from the voltage reference Zener diode CR305, balanced differential transistor pair Q301, Q302 and amplifier Q303.

### 15 V Emitter Supply

The 15V Emitter Supply is used solely to control the current in the transistor under test by means of the front panel I ADJ., potentiometer R516 and current limiting resistors R528 through R532 as selected by the MA range selector switch.

The operation of this supply is the same as the 26V general supply and need not be repeated here.

### VTVM Supply

The VTVM Supply is used to supply a positive 105V and a negative 105V source for the two vacuum tube voltmeters. V502 is used to measure the collector current of the test transistor and V501 is used to measure the emitter-collector voltage of the test transistor, and also to control the regulated collector power supply. Its operation is as follows:

AC voltage from secondary #5 is rectified in the voltage doubling circuit consisting of CR101, CR102 and capacitors C102 and C103. This voltage is filtered by the R C filter consisting of R101, C104, and R102 and VR tubes V101, V102. The VR tubes also regulate this voltage and provide a midtap supplying both a positive and negative 105V. This midtap is connected to a point on the test transistor collector supply buss. The minus 105 is also separately filtered by R103, C105 and supplies minus 105V for the collector supply vacuum tube voltmeter.

### Current Meter Circuit

The current meter is basically a high impedance, 1 volt, vacuum tube voltmeter and measures current by measuring the voltage drop across a resistor in series with the test transistor. This resistor value is selected by means of S503 for the different collector current and leakage current ranges.

Vacuum tube V502 is a twin triode arranged in a balanced differential cathode follower circuit driving a meter (M502) and calibrating resistor (R538) connected between the two cathodes. This circuit is calibrated to read full scale when 1 volt is applied between the two tube grids. Switch S501L and S501M serve to maintain proper polarity when the NPN/PNP switch is changed.

### Voltmeter Circuit

The voltmeter is also a high input impedance vacuum tube voltmeter circuit which also serves as a servo control loop to maintain a pre-set voltage between the emitter and collector of the test transistor. Its operation is as follows:

Vacuum tube V501 is a twin triode arranged in a balanced differential cathode follower circuit driving a meter (M501) and resistor connected between the two cathodes. The meter resistors are switched for each voltage range and calibrated to give correct meter indication for each voltage range, 1 volt through 30 volts, when this voltage is applied between the two grids. S501E and S501F serve to maintain proper polarity when the NPN/PNP switch is changed. The cathode resistor of the right half section of V501 (see schematic C3105) consists of V ADJ. resistor R512 and fixed resistor R513. The moveable arm of R512 permits the servo control line to be offset by the desired collector voltage and thus control the collector supply at any level desired between 0 and 30 volts.

### Collector Supply

The Collector Supply is a variable regulated power supply adjustable from 0 to 30V capable of supplying 30 milliamperes. It is used to supply collector voltage to the transistor under test. Theory of operation is as follows:

AC voltage is supplied by secondary winding #3 of T101. This voltage is rectified by a bridge rectifier CR203, CR204, CR205 and CR206. C203 is the filter and storage capacitor. This unregulated voltage is applied to the collector of pass transistor Q205. The base

of Q205 is controlled by the differential balanced transistor pair Q201, Q202 and emitter follower Q203. CR208 and CR209 are clamping diodes and prevent excessive voltages or currents from damaging the transistors. These diodes are normally non-conducting. Voltages for the control and differential pair transistors are supplied by secondary winding #4 of T101, half wave rectifiers CR201, CR202 and capacitors C201 and C202. CR207 is a Zener diode and regulates the collector voltage of Q201 and Q202. Q204 is used to limit the maximum current which can be drawn from the power supply and operates as follows. The base of Q204 is normally held approximately 0.75V positive with respect to its emitter by the current through R210 and the voltage drop across the forward biased diode CR212 which is connected to the emitter of the pass transistor Q205. This bias prevents Q204 from conducting and permits normal operation of the collector supply. When currents in excess of approximately 35 milliamperes is drawn from the emitter of Q205 the voltage developed across R211 and R212 exceeds this 0.75V and transistor Q204 begins to conduct and clamps the base of Q203 to the negative regulated buss cutting off the drive to pass transistor Q205 and thus limiting the maximum current to a safe value. CR210, CR211 and the emitter base potential voltage drops serve to supply collector voltage for the current limiting transistor Q204. CR213 is a back biased diode to prevent damage and lockout of the control if reverse voltages are applied to the supply. Operation of the servo line and collector voltage level is as follows: Assume operation is for NPN configuration. The negative side of the collector supply is grounded via NPN/PNP switch S501A. The positive side is connected to the test transistor collector via S501B, current range selector switch S503A, function switch S505A, transformer T501, interlock switch S504 and S505C. The collector voltage is sampled and applied to the voltmeter grid (right hand section Sec. C-3105) via isolating resistor R533 and switch S501E. The voltage at the emitter is sampled and applied to the other voltmeter grid causing an unbalanced condition of the two cathode followers by the amount of this voltage (see voltmeter operation). As the collector supply voltage is dependent on the voltage difference between the bases of the differential balanced transistor pair Q201, Q202 and as these bases are connected across the cathode V501 and cathode resistor V. ADJ. (R512) the output voltage will shift in a direction to maintain a balanced condition in these transistors. The collector voltage will approximately be equal to the voltage drop between the cathode of V501 (right section) and the arm of V. ADJ. (R512). Operation in the PNP transistor position is similar but supply and test transistor voltages are reversed in polarity.

### 4 KC Oscillator

The 4 KC Oscillator is used to supply an accurate reference signal at the base of the transistor under test and also to operate the automatic gain control system which allows accurate noise measurements independent of the Beta of the transistor under test. Operation is as follows: Negative voltage is supplied from the 26 volt general supply through R601 and voltage regulating Zener diode CR601. The oscillator is of the LC type using the primary of a stable torroid transformer and capacitors C601, C602 and C603 as the frequency determinates. This frequency is tuned to 4.00 KC. The transistor Q601 operates in a grounded base configuration and obtains its emitter excitation from a capacitance divider network approximately 30:1 consisting of C601 and C602. This provides a low impedance drive for the emitter of Q601. The collector output drives from a tap on the transformer T601 also a relatively low impedance point and R604 to further minimize any collector loading on the LC tank circuit. This results in an extremely stable oscillator whose level is controlled by the stable Zener voltage of CR601 and is independent of transistor characteristics or supply voltage. Output voltage at 4.00 KC is obtained from a very low impedance winding and adjustable by means of R607 to a value of 5.1 millivolts at the Beta calibration jack J501.

### Base Selector Switch

The base selector switch located on the test transistor panel provides a selection of impedance for the base of the transistor under test. In the $E_N$ position the base is returned to ground via R544 a 1 ohm resistor. This resistor is part of a divider network R544 and R546 supplying the low level carrier signal necessary to operate the AGC system and serves as the noise level reference generator. The 500 and 1K positions permit measuring the "Noise Figure" of the transistor test and the $I_N$ position permits direct measurement of the input current noise. S505F when in the "$\beta$" position permits driving the test transistor base at a higher level (5.1 millivolts)via the high Q tank circuit L501, C509 and C510 acting as a constant current source at 4 KC to permit direct Beta measurements.

### T 501

Transformer T501 is a special band pass current transformer designed to permit transfer of the noise current and 4 KC carrier signal from the transistor under test to amplifier #1. The transformer has a bandpass from 100 cycles to 100 kilocycles.

### Amplifier #1

Amplifier #1 is a three stage extremely low noise transistor amplifier utilizing NPN, PNP, NPN configuration. Q701 operates as a grounded base amplifier, the emitter impedance properly terminating the secondary winding of T501. Q702 and Q703 operate as grounded emitter amplifiers with maximum overall negative feedback, assuring stable gain and low output impedance to drive the following compressor.

### Compressor #1 and #2

The compressors #1 and #2 operate in an identical manner and will be discussed together. The compressor serves as a variable attenuator consisting of resistor R802 and a pair of transistors Q801, 802 connected as diodes operating in parallel to alternating current which act as the lower leg of a voltage divider network. As the AC impedance of a diode is inversely proportional to the DC current, the impedance of this lower leg of the network is approximately $= \frac{13 \text{ ohms}}{I_{dc} \text{ in milliamperes}}$ and is linear over a current range of several hundred to one. Compressor #2 comprising Q807, Q808 and R816 act in a similar manner, the amount of signal compression being controlled by AGC amplifier and reference network.

### Amplifier #2

Amplifier #2 is typical of several amplifiers used in this instrument, conventional transistor circuitry is employed, Q803 is the input PNP transistor grounded emitter configuration. Q804 is NPN driver for the complementary symmetry push pull output pair Q805 and Q806. Overall negative feedback serves to stabilize the overall gain, reduce crossover distortion and provide a low impedance circuit. Voltage gain is approximately 80 and incorporates a temperature compensating resistor R808 to compensate for the temperature characteristics of the diode compressors.

### Amplifier #3

Amplifier #3 is identical to Amplifier #2 and is used to drive the 4.00 KC notch filter of the AGC system and the variable attenuators of the noise filter systems.

### 4 KC Notch Filter

The 4 KC Notch or AGC filter is a series resonant LC filter of high "Q", consisting of C905, C907 and L901. This filter serves a dual purpose. It removes the major portion of the 4 KC oscillator carrier signal from the noise filter spectrum and drives the compressor amplifier.

### Compressor Amplifier

The compressor amplifier while basically similar to Amplifier #2 and #3 operates in a slightly different manner. As the 4 KC notch filter requires a low terminating impedance to maintain a reasonable tank circuit Q the base of Q1007 is grounded to ac and the emitter feedback point, which has an extremely low impedance, is used as the input. Thus Q1007 operates as a PNP grounded base amplifier to drive Q1006 as an NPN grounded emitter amplifier which in turn drives the complementary symmetry pair Q1004 and Q1005.

### Compressor Driver

The function of the Compressor Driver is to convert the 4 KC carrier signal to a DC current to control the signal compressors maintaining the overall noise loop gain to a constant. Operation is as follows: CR1002 and CR1003 rectify the 4 KC carrier signal. C1002, R1006 and C1001 filter the DC and form the proper time constant for the AGC system. The rectified DC signal is applied to the base of Q1003 of the differential transistor pair. The base of Q1002 is clamped to the Zener voltage level of CR1001. This leaves Q1001 in a cut-off condition until the rectified 4 KC carrier level is equal to the Zener voltage. Q1001 then turns on and maintains sufficient current to the compressors to maintain this level. M1001 is a 5 milliampere meter calibrated in terms of Beta and thus measures the current gain of the transistor under test when the function switch is in the "$\beta$" position.

### Filter Attenuator

The filter attenuators for all noise channels are identical and receive their common signal from the output of Amplifier #3 through resistor R913 which permits notching the 4 KC carrier from the noise spectrum. These attenuators are of the simple ladder type of 3,000 ohms impedance.

### 1 KC Filter Amplifier

This amplifier serves to increase the noise level, provides a high input impedance to eliminate loading the attenuator and provide a low impedance for the following noise filter. The operation of this amplifier is identical with that of Amplifier #1 and #2 with the exception of the 27 ohm gain determining resistor R1313 which is a stable non-temperature sensitive type as temperature/gain correction is not required at this point.

### 1 KC Filter

The purpose of the bandpass filter is to sample the noise spectrum at 1 KC and reject all other noise or signals. The filter is a three stage maximumly flat type using stabilized torroidial coils and mylar tuning capacitors, hermetically sealed at the factory. No further adjustments are required.

### Meter Amplifier

The meter amplifier (Ass'y #3159) and meter rectifier board (Ass'y #3160) will be discussed together. The amplifier is similar in operation to the previous amplifiers. Q1401, a PNP transistor drives Q1402 a NPN type grounded emitter which in turn drives Q1403 and Q1404 a complementary symmetry pair supplying a low impedance drive for the meter rectifiers CR1401 and CR1402. The noise signals are rectified and measured by M1401 a 500 microamperes meter. The meter-rectifier return is applied to the emitter of Q1401 providing maximum negative feedback and linearity.

CR1403 is a forward conducting diode to protect the meter against overloads. R1415 permits adjustment of the DC analog to 1 volt DC which is available at J1402. R1413 the screw driver adjustment in the rear of the noise channel permits adjustment and calibration of the noise channel. J1401 permits oscilloscope observation of the noise envelope at the filter frequency.

### 10 KC and 100 KC Noise Channels

The 10 KC and 100 KC noise channels are identical to the 1 KC channel with the exception of the filter frequency and the roll off capacitor on the input of the meter amplifier.

### 100 Cycle Amplifier and Filter

The 100 Cycle Amplifier is quite different, being a three section synchronously tuned type utilizing a double emitter follower or grounded collector stage at the input and between each filter section to provide power gain, isolation and high stability. The inductors are highly stable toroidal type, hermetically sealed at the factory and adjusted to resonate with C1102, C1103 and C1104. No further adjustment is required.

### 100 Cycle Meter Amplifier

The 100 cycle meter amplifier and rectifier (Ass'ys 3155 and 3156) operate the same as the 1 KC meter amplifier and meter rectifier and need not be again discussed here.

# SECTION 6

# MAINTENANCE AND CALIBRATION

The components and transistors in the Model 310 are conservatively rated and should provide long and trouble free service. If, however, the instrument has been damaged and recalibration or alignment is required, the following instructions should be followed explicity, or the instrument returned to the factory. Instructions are given on the Warranty page for the procedure to be followed should it be desired to return the instrument for any reason.

Although the Model 310 is a complex instrument, trouble shooting can readily be done in sections as indicated in the block diagram, Fig 6-1. Standard transistor servicing care should be used throughout.

Do not change any adjustments without a thorough knowledge of the circuit and the functions of the adjustment.

Transistors can be easily damaged with large transient voltages. Therefore, take great care not to short any terminals when making measurements on the printed-circuit boards. In soldering to the boards, have the iron only hot enough to make a rapid clean solder joint. Do not apply any force which would tend to push the copper away from the board.

NOTE: Refer to Figs. 6-4, 6-5 and 6-6 for component locations.

1. *Removal from Case.*

To remove the unit from the case, proceed as follows:

a. Remove the two right-hand rubber feet and the four binder head screws from the bottom of the case.

b. Slide the unit gently out of the front of the case.

2. *Changing Input Voltage.*

This instrument has been designed to operate from a 117 V.A.C. or a 234 V.A.C. power source. The plate on the rear of the instrument near the power cord indicates the voltage and frequency at which the instrument should be operated.

Should it be desired to change the input voltage,

1. Remove the instrument from the case.

2. Change the transformer primary connections by moving the jumpers on the 4 terminal barrier strip located near the power cord (See Fig. 6-1).

3. Change the fuse. For 117 V.A.C. operation, the fuse should be ½ Amp. Slow Blow; for 234 V.A.C. operation the fuse should be ¼ Amp. Slow Blow.

4. Reverse the plate located near the power cord to read the correct voltage.

3. *Power Supplies.*

Apply line power to the unit. The pilot light should light indicating the power transformer is operating.

**General Power Supply**

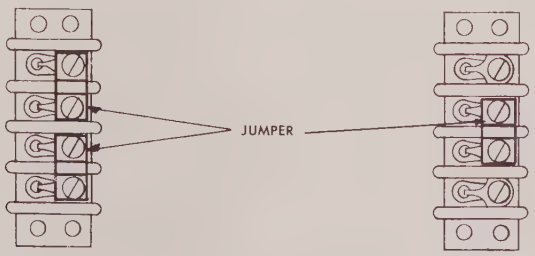
a. Measure voltage at the General Power Supply plug-in board (assembly 1868) between terminal "A" and ground.

b. Adjust R301 for minus 26V DC at this point.

**Emitter Supply**

a. Measure voltage at the Emitter Power Supply plug-in board (assembly 1869) between terminals "A" and "F".

b. Adjust R401 located on assembly 1869 for 15V DC. Terminal "A" is minus.




**For 117 V.A.C. operation** **For 234 V.A.C. operation**

**FIGURE 6-1. INPUT VOLTAGE BARRIER STRIP**

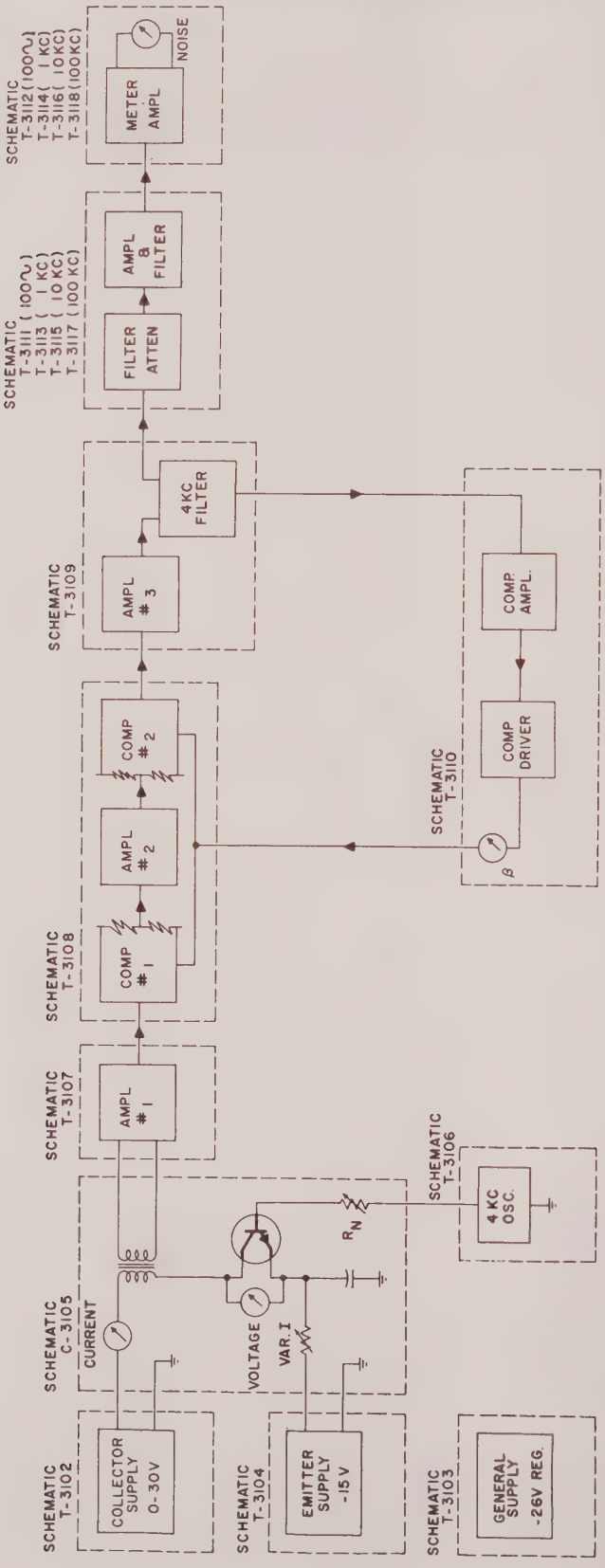



FIGURE 6-2. DETAILED BLOCK DIAGRAM

### Collector Supply

a. Insert a transistor capable of handling 40 milliamperes in the front panel test jig socket.
b. Connect a DC milliammeter in series with the collector lead.
c. With shield cover and interlock switch open, set R539 screw driver adjustment control (located just below and to the right of the CURRENT meter) for zero current meter indication.
d. Set front panel controls as follows:
   - FULL SCALE VOLTS switch at 3
   - V. ADJ. for approximately 3 volts
   - CURRENT RANGE switch 30 MA
   - I. ADJ. approximately mid range
   - FUNCTION switch to NOISE
   - BASE SELECTOR switch to $E_n$ position
e. Depress shield cover interlock switch
f. Advance I. ADJ. current control until milliammeter indicates approximately 34 milliamperes.
g. Adjust R212 located on Collector supply plug-in board (assembly 1871) until voltmeter indicates a loss of power supply regulation.

### Current Meter Calibration

a. With a milliammeter in series with the test transistor collector and approximately 3V on collector, set I. ADJ. control for 10 milliamperes collector current.
b. Adjust R538 located on assembly 1865 for a current meter indication of 10 milliamperes with the current selector switch in the 10 MA position.

### D.C. Voltmeter Calibration

a. Adjust mechanical zero with instrument turned off.
b. Turn instrument on and allow several minutes for voltages to stabilize.
c. Place a short circuit jumper wire between emitter and collector of the test transistor socket.
d. Set controls as follows:
   - Function switch in NOISE position
   - V. ADJ. full counterclockwise
   - Current range switch to 30
   - I. ADJ. full counterclockwise
e. Depress test transistor interlock switch.
f. Adjust screw driver adjustment R507 (located below and to the right of the *VOLTAGE* meter) for approximately zero indication of the *CURRENT* meter.
g. Remove short circuit and connect a DC voltmeter between emitter and collector of the test transistor socket.
h. Depress interlock switch and set V. ADJ. control to obtain 1 Volt.
i. Adjust R508 on assembly 1865 for a VOLTAGE meter indication of 1 Volt with the FULL SCALE VOLTS switch set to 1.
j. Repeat for R509 through R511 for voltage ranges 3 through 30.

### 4 KC Oscillator

a. Insert a phone plug partly into the $\beta$ CAL. jack (located in rear of the instrument), only far enough to make contact, but DO NOT break the normally closed contact of this jack.
b. Measure the voltage at this point and adjust R607 on assembly 1872 to obtain 5.1 millivolts RMS.
c. Measure the frequency of this signal and adjust C603 assembly 1872 until frequency is 4.00 KC.

### Compressor Filter

a. Insert a transistor in the test jig.
b. Apply normal operating voltage and current.
c. Set function switch to NOISE position.
d. Connect a high impedance DC voltmeter (approx. 4V) between either terminal of the Beta meter (ass'y 1865) and ground. (Beta meter is negative polarity respect to ground.)
e. Tune compressor filter C907 (ass'y 1872) for a maximum voltmeter indication.

### Base Input Tank Circuit Adjustment

a. Insert a transistor in the test jig.
b. Apply normal operating voltage and current.
c. Set function switch to "$\beta$" position.
d. Connect a high-impedance DC voltmeter between either terminal of the Beta meter (assembly 1865) and ground.
e. Tune base input tank circuit (C509, ass'y 1864) for minimum voltmeter indication.

### Beta Meter Calibration

a. Set controls as follows:
   - Function switch in "$\beta$" position
   - I. ADJ. full counterclockwise
   - V. ADJ. full counterclockwise
b. Insert a short circuit jumper between base and collector of the test transistor socket.
c. Close interlock switch.
d. Insert a plug in the $\beta$ CAL. jack completely (to break the circuit of the internal 4 KC oscillator).
e. Apply a 510 millivolt 4.00 KC signal to the $\beta$ CAL. jack.
f. Adjust R1009 (ass'y 1878) for a Beta meter indication of 100.

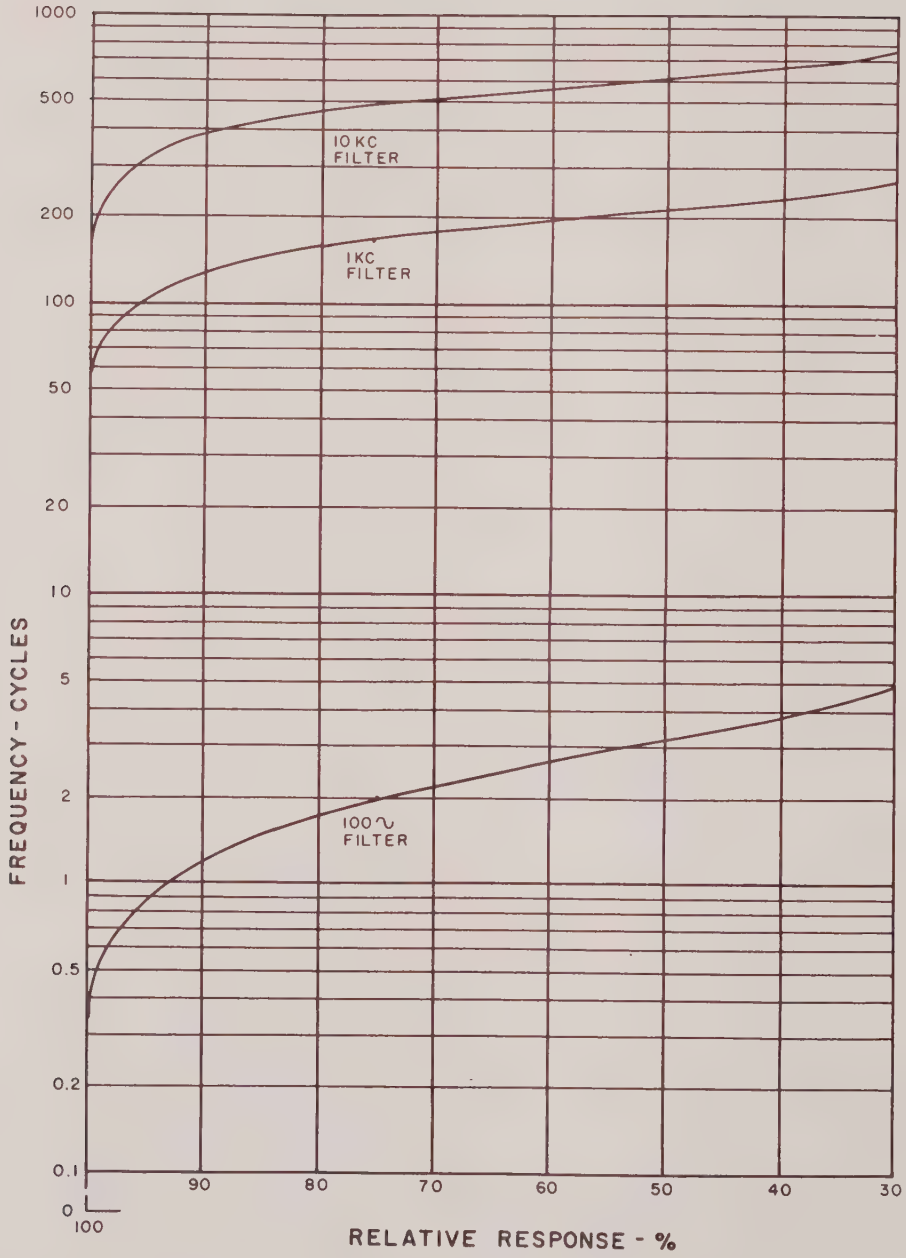



FIGURE 6-3. TYPICAL FILTER HALF BANDWIDTHS

### Noise Meter Calibration

Each noise filter and amplifier must be calibrated separately, which involves the noise bandwidth of each filter, meter correction for noise signals and an attenuator constant. The attenuator constants have been computed and calibrating voltages for each filter are listed below. Typical bandwidth curves are shown in Fig. 6-3.

To calibrate, proceed as follows:

a. Set FUNCTION switch to NOISE position.
b. Connect an audio oscillator to the NOISE CAL jack (J502), inserting he phone plug completely.
c. Tune oscillator to the filter frequency.
d. Adjust oscillator level to the value for the filter concerned.

| | | SN. 105 |
|---|---|---|
| 100 cycle = | 2.48 mv | 2.5 mv |
| 1 KC = | 16.5 mv | 17.04 mv |
| 10 KC = | 26.6 mv | 29.65 mv |
| 100 KC = | ..... mv | |

e. Adjust NOISE CAL. screw driver adjustment in rear, behind the filter concerned to obtain full scale meter indication with the FULL SCALE meter switch in the 1 position.
f. With the calibrating signal still applied measure the DC voltage at the NOISE ANALOG jack for the filter concerned and adjust the screw driver adjustment (located on the printed-circuit board at the rear of the noise meter concerned) for 1 Volt DC for full scale indication.
g. Repeat the above procedure for the other noise-filter channels using the calibrating signal levels listed for each channel.

NOTE: When making the above adjustments, a high frequency transistor with an Alpha cutoff frequency of several megacycles should be used in the test jig, and the base selector switch should be in the $E_N$ position to prevent errors at the higher frequencies due to transistor input capacitance.

### THRESHOLD NOISE MEASUREMENT

With the known amplification factor method of calibration utilized in the Model 310, internal amplifier gain is highest when the test transistor gain is lowest. This condition occurs at low collector current when the FUNCTION switch is in the NOISE position.

Amplifier system noise is completely masked by the thermal noise from the 10,000 ohm base resistor when measuring $I_N$. (Correction for the 10K thermal noise is described on page 3-0 under OPERATIONAL HINTS.) Amplifier system noise may become an important factor when measuring $E_N$ on a very quiet transistor at very low collector current. Typically $E_N$ readings can be taken directly with less than 1db error due to system noise down to collector currents of approximately 50 microamperes on the 10KC filter, 100 microamperes on the 1KC filter and 200 microamperes on the 100 cycle filter.

A method of determining system noise follows so that $E_N$ readings may be corrected if required in the very low collector current area.

The measured noise voltage ($E_N$) is corrected through the use of the following equation:

$$\text{Corrected } E_N = (\text{measured } E_N^2 - \text{system } E^2)^{1/2}$$

In general, system noise will vary approximately inversely with collector current and will be different for each of the three frequencies monitored at a fixed collector current.

The procedure for measuring system noise for a particular DC collector current is as follows:

a) Set Model 310 front panel FUNCTION switch to NOISE, I. ADJ. full counterclockwise and V. ADJ. full counterclockwise.
b) Connect the ground sides of two external audio oscillators to the grounding braid between the test jig cover and base plate of the Model 310. Connect the high sides of both oscillators through separate 1 megohm resistors to the collector pin of the test socket.
c) Tune one oscillator to 1KC and set its output voltage to the magnitude given by the following equation:

$$\text{1KC osc. voltage} = \left(\frac{I_C}{.025}\right)\left(\frac{\text{1KC cal. voltage}}{A}\right)\left(10^6\right) \text{ volts}$$

WHERE:

$I_C$ = the particular DC collector current in amperes at which system noise is to be measured.

1KC cal. voltage = 1KC cal voltage given on page 6-5 of the instruction manual.

A = .....

d) Tune second oscillator to 4KC and close test jig interlock switch.
e) Increase output voltage of 4KC oscillator until 1 KC NOISE meter reading comes down to approximately full scale on the 1 position of the FULL SCALE range switch.
f) Fine tune 4KC oscillator frequency for *minimum* reading on IKC NOISE meter.
g) Adjust 4KC output voltage for precisely full scale reading on IKC NOISE meter.
h) Remove IKC oscillator and series resistor and read system noise (at $I_C$ used in above equation) on each of the NOISE meters.

NOTE: System noise at particular values of $I_C$ are meaningful only when the transistor to be tested has the following qualifications: Beta greater than 10 and $I_C$ much greater than $I_{CBO}$.

System noise measured as directed above is a noise voltage referred to the base of the transistor under test. An equivalent noise current in the collector of the transistor under test can be obtained through the use of the transconductance equations:

$$\Delta i_c = gm\ (\Delta e_b) \qquad gm = \frac{I_C}{.025}$$

WHERE:

$\Delta i_c$ = equivalent collector noise current.

$\Delta e_b$ = measured system noise voltage referred to the base of the transistor under test.

$I_C$ = the particular DC collector current in amperes at which system noise was measured.

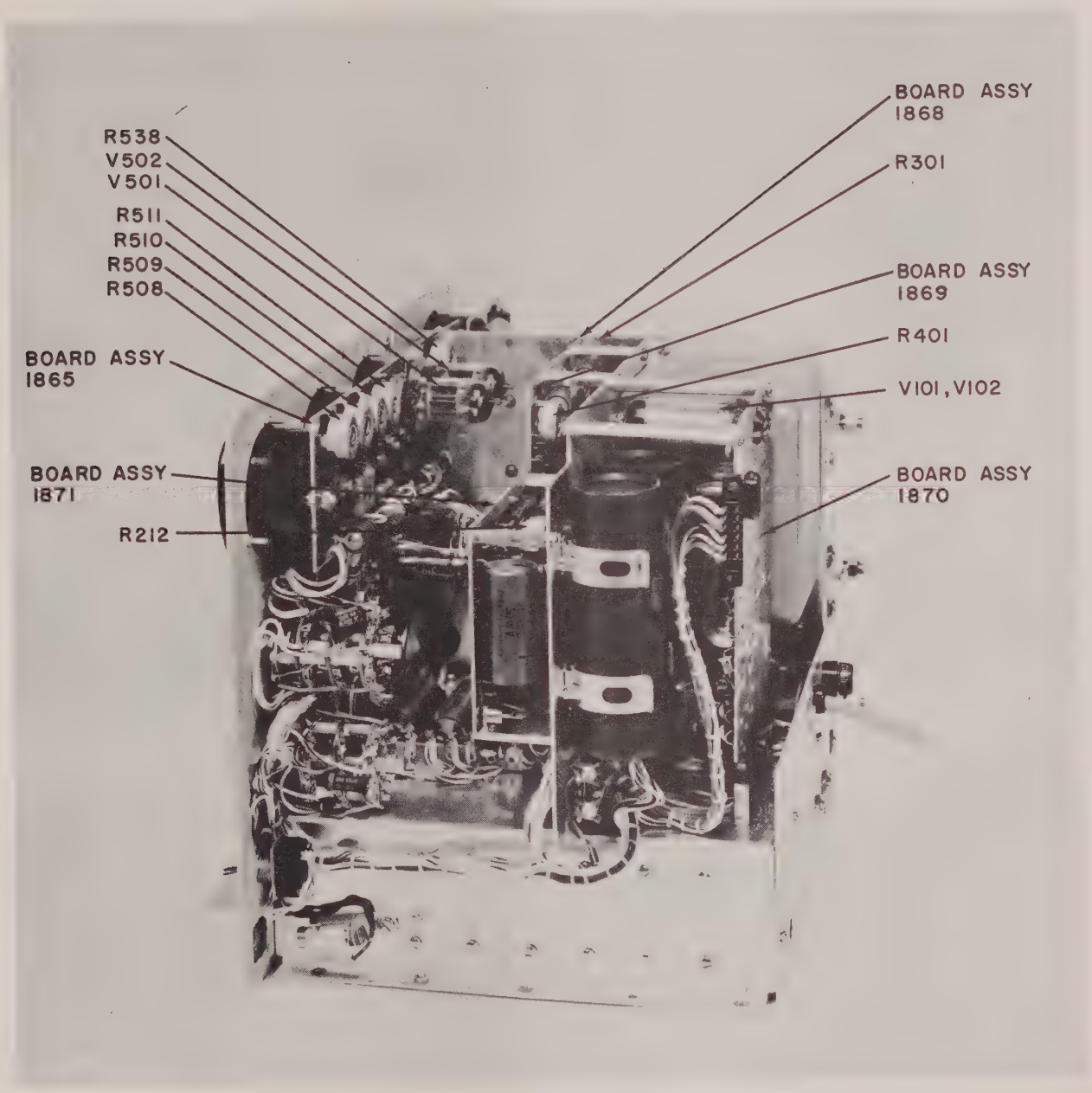



FIGURE 6-4. INTERNAL VIEW FROM RIGHT SIDE

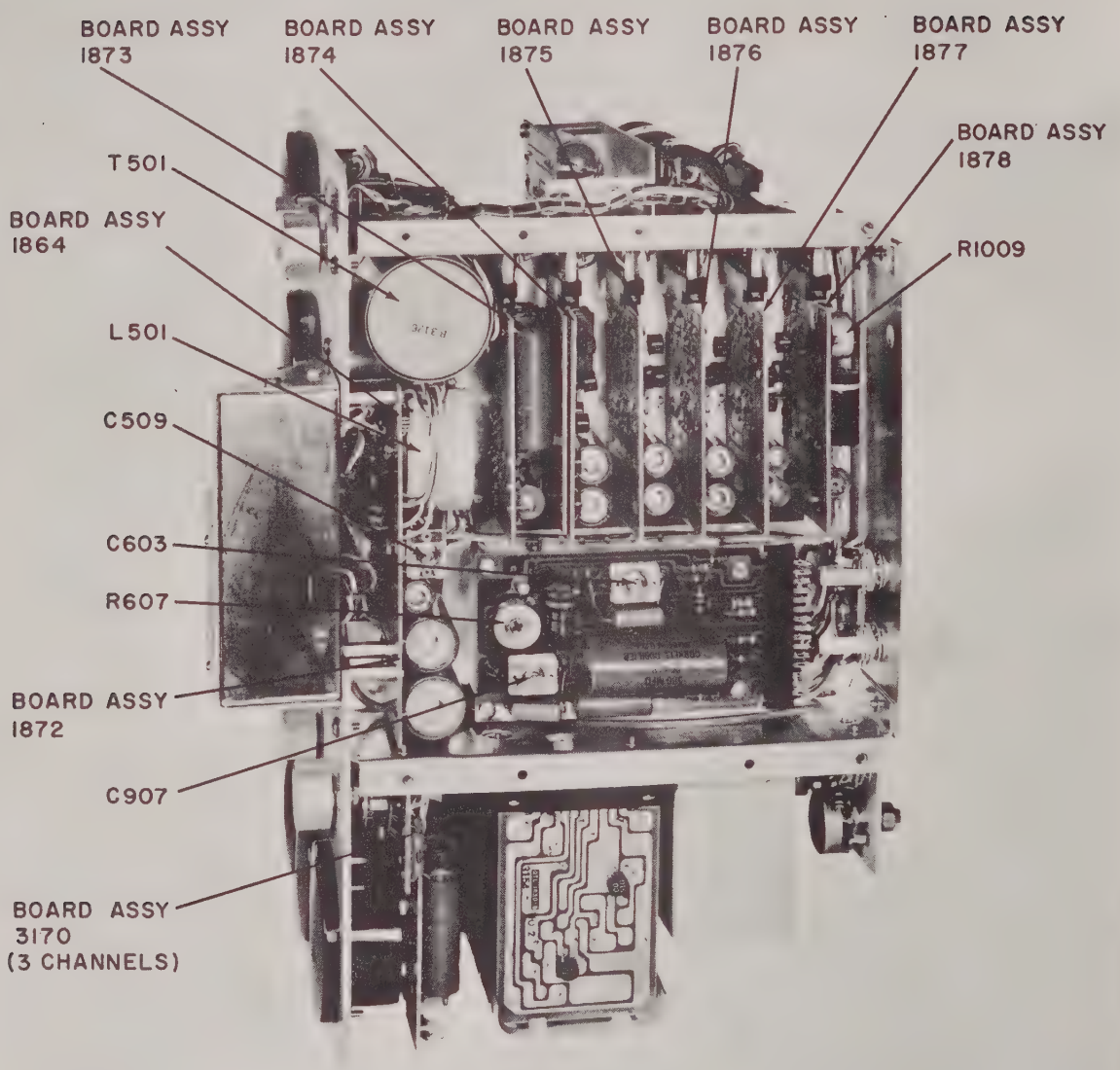



FIGURE 6-5. INTERNAL VIEW FROM BELOW

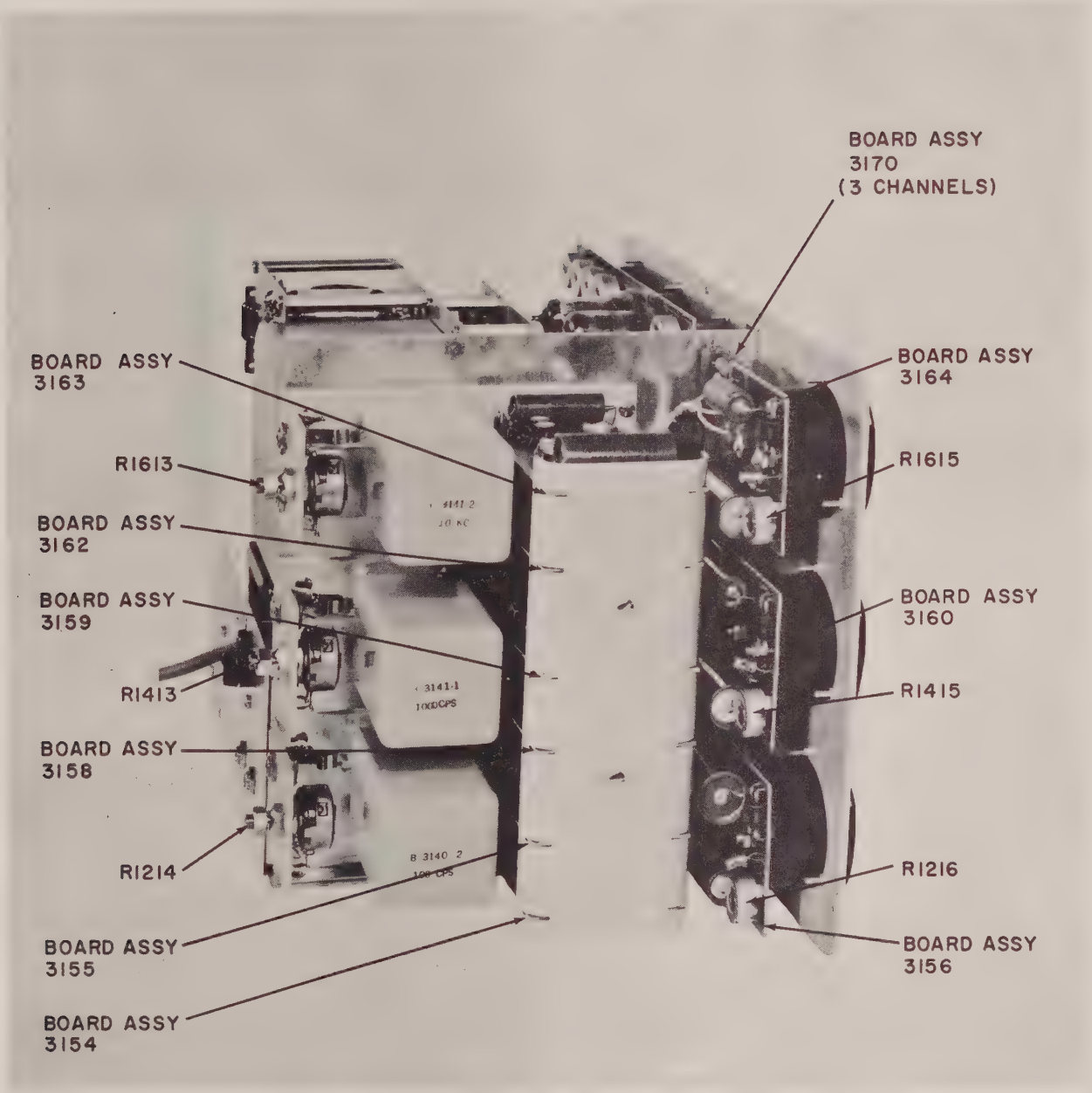
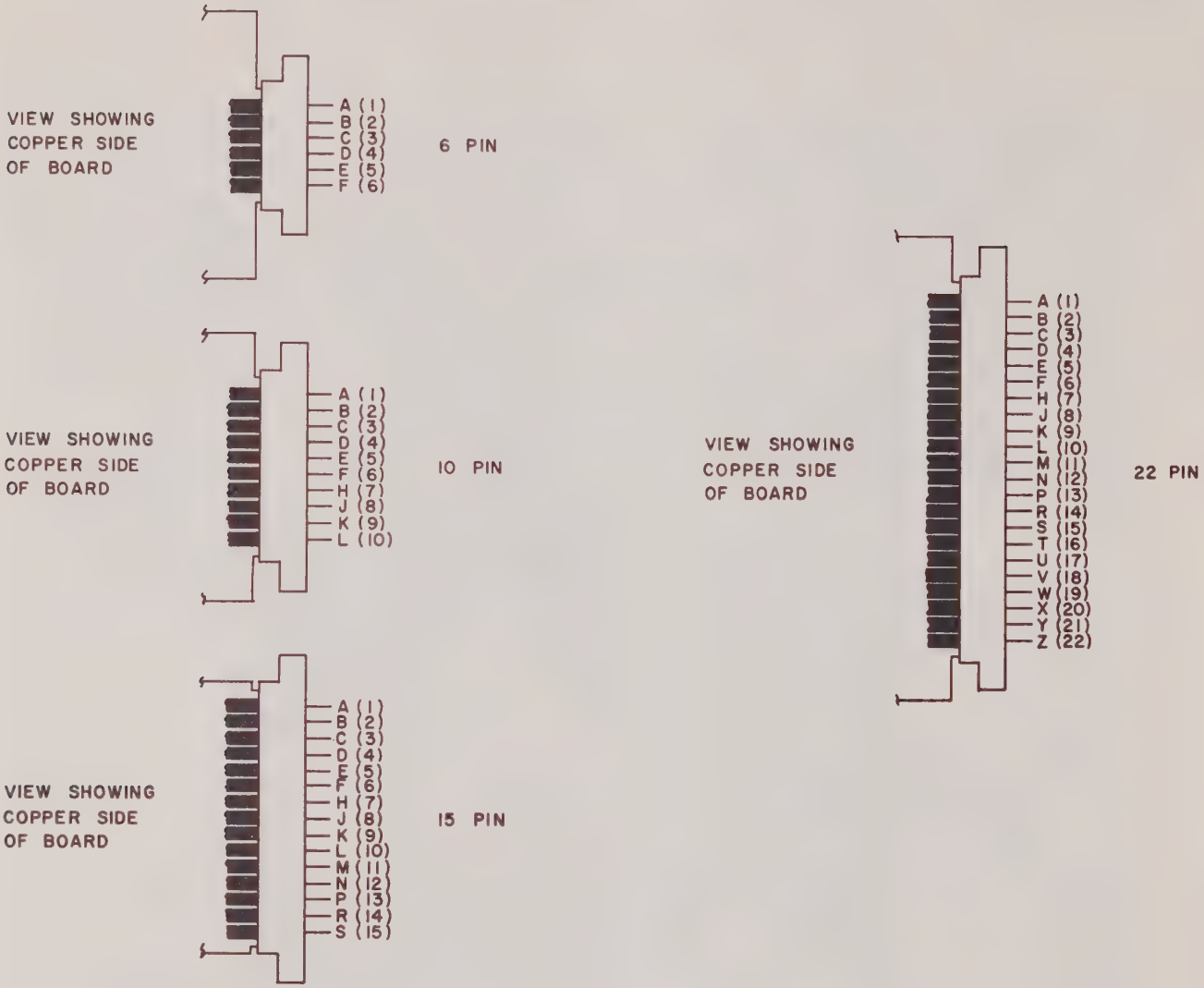



FIGURE 6-6. INTERNAL VIEW FROM ABOVE




PRINTED CIRCUIT BOARD CONNECTOR LUG IDENTIFICATION

## SCHEMATIC LEGEND

k = 1000

⊘ = Screw Driver Adjustment

▭ = Front Panel Control

* = Factory Select

Unless Otherwise Specified:

All Resistances in Ohms

All Resistors 1/2 Watt

All Capacitances in Microfarads

# SEMICONDUCTOR LEGEND

Changes and improvements in the semiconductor products available for commercial use necessitate type changes from time to time. To eliminate confusion and costly paperwork, many of these changes will be covered in the following legend. The purpose of this legend is to acknowledge the fact that the type number on a semiconductor found in a piece of equipment will not necessarily correspond with the type number given on the schematic diagram.

The legend is not intended to be an interchangeability list although in many cases good quality components* within a given category may be substituted with acceptable results. Normally, replacements should be made using components having the same type number as the component being replaced.

Those components bearing an asterisk on the schematic diagram are factory selected components and should be obtained from Quan-Tech Laboratories.

*It should be noted that the incoming inspection procedure followed at Quan-Tech Laboratories includes noise screening on most semiconductors.

| TYPE # ON SCHEMATIC | TYPE # IN EQUIPMENT |
|---|---|
| T1480 | 2N1613 |
| T1494 | 2N1613 |
| 1N703 | 1N748 |
| 1N709 | 1N753 |
| 1N2859 | 1N3253, 1N3254 |
| 1N2862 | 1N3254 |
| 1N482A | 1N3604 |
| 1N3253 | 75A4 |
| 1N3254 | 75A4 |
| 2N396A | 4JX1G759, 4JX1D653, 2N3644 |
| 2N414 | 2N396A, 4JX1G759, 4JX1D653, 2N3644 |
| 2N929 | 2N0N2, A642, 2N3566, A322, A324 |
| 2N1515 | 2N3644 |
| 2N1613 | 2N3566, 2N3643 |
| 2N2219 | 220N2, A642, 2N3566, A322, A324 |
| 2N2603 | 2N3250 |
| 2N3250 | 2N3644 |
| 2N270 | 2N3644 |
| 2N1306 | 2N3566 |
| 2N1304 | 2N3566 |
| 2N3250 | 2N3251 |
| UC240 | 2N4869, 2N3819 |
| 2N3644 | 2N3250, 2N3251 |
| 2N3566 | 2N3643 |

## SCHEMATIC LEGEND

k = 1000

⊘ = Screw Driver Adjustment

▭ = Front Panel Control

* = Factory Select

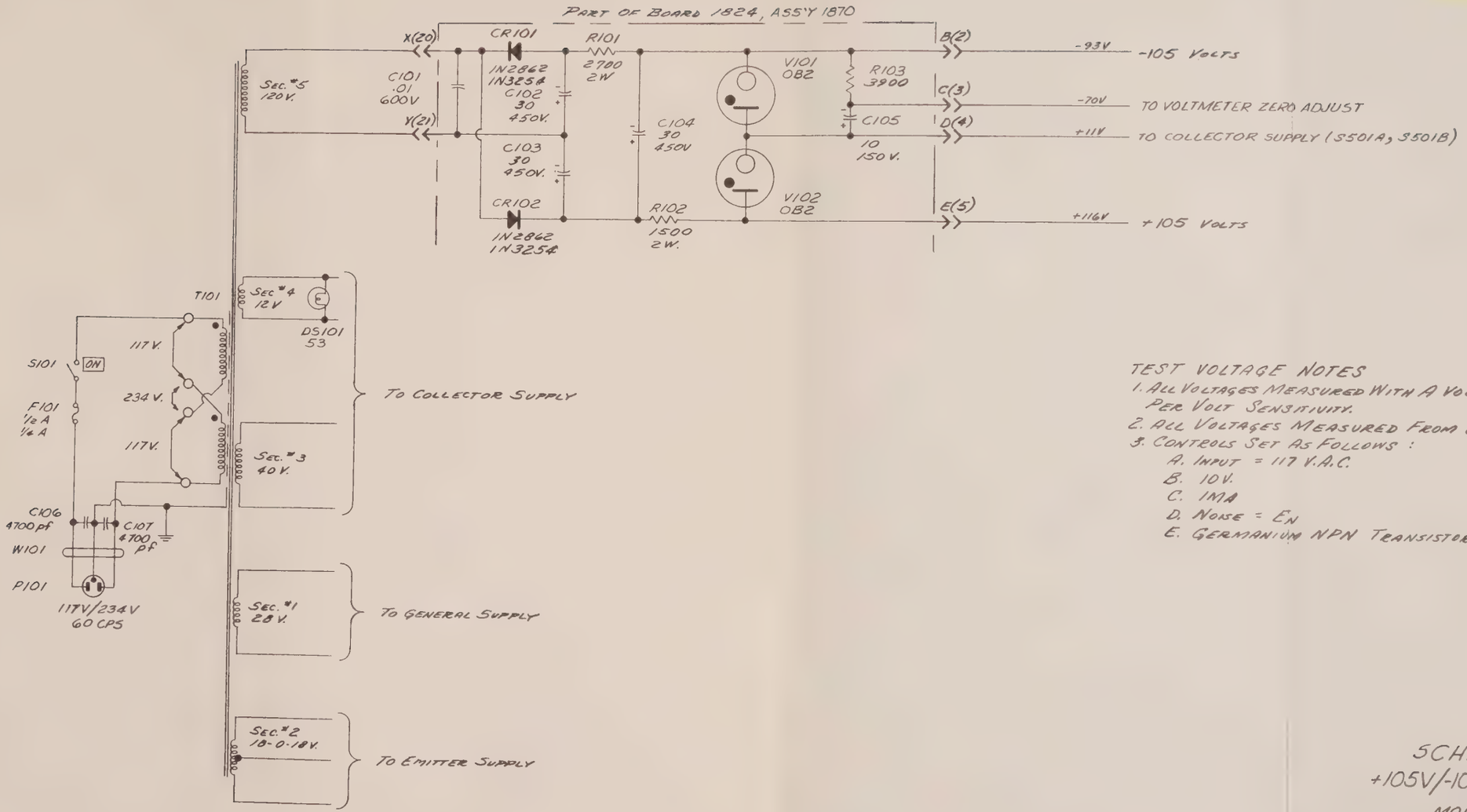
Unless Otherwise Specified:

All Resistances in Ohms

All Resistors 1/2 Watt

All Capacitances in Microfarads

8/20/69



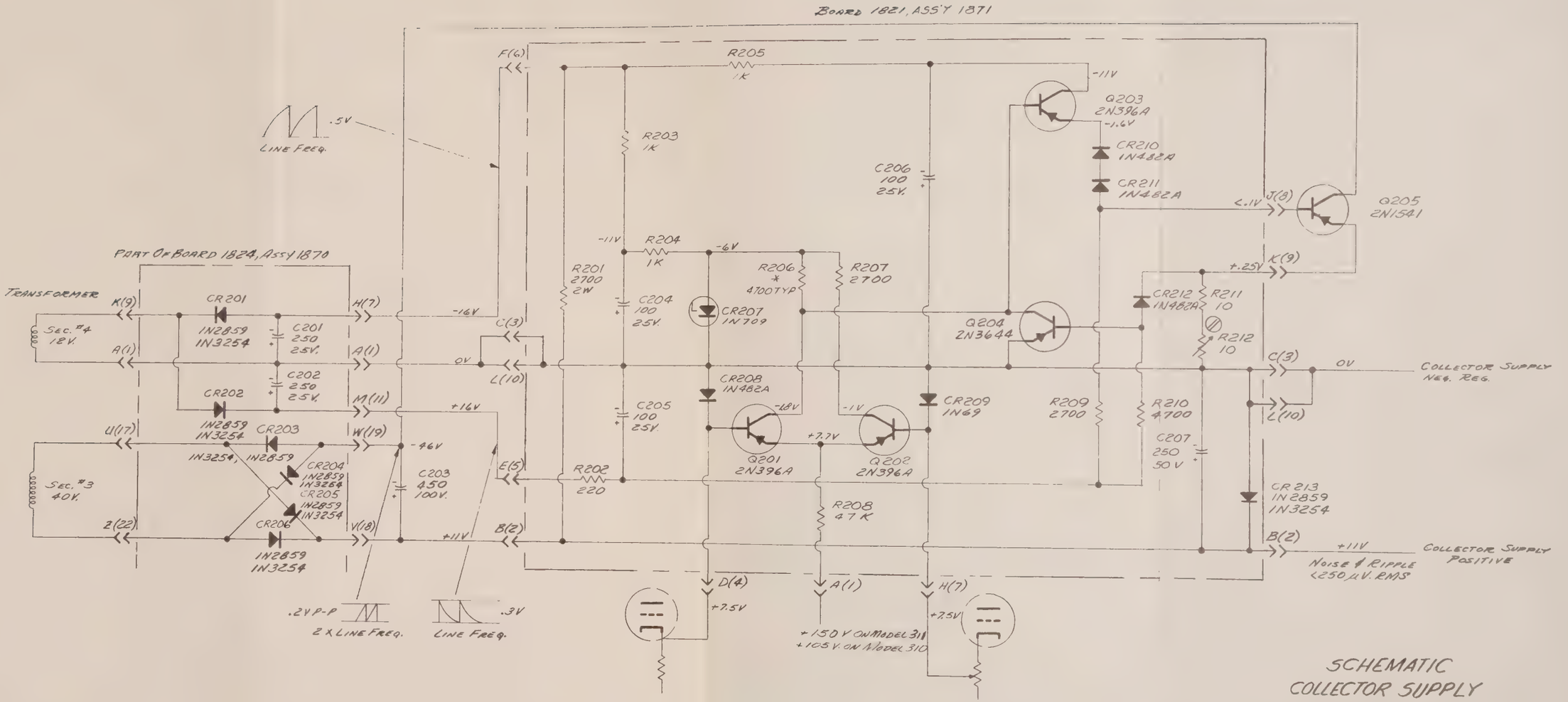

TEST VOLTAGE NOTES

1. ALL VOLTAGES MEASURED WITH A VOLTMETER HAVING A 20,000 OHMS PER VOLT SENSITIVITY.
2. ALL VOLTAGES MEASURED FROM GROUND.
3. CONTROLS SET AS FOLLOWS :
   - A. INPUT = 117 V.A.C.
   - B. 10V.
   - C. 1MA
   - D. NOISE = $E_N$
   - E. GERMANIUM NPN TRANSISTOR IN JIG

# SCHEMATIC
## +105V/-105V SUPPLY

MODEL 310
MODEL 311

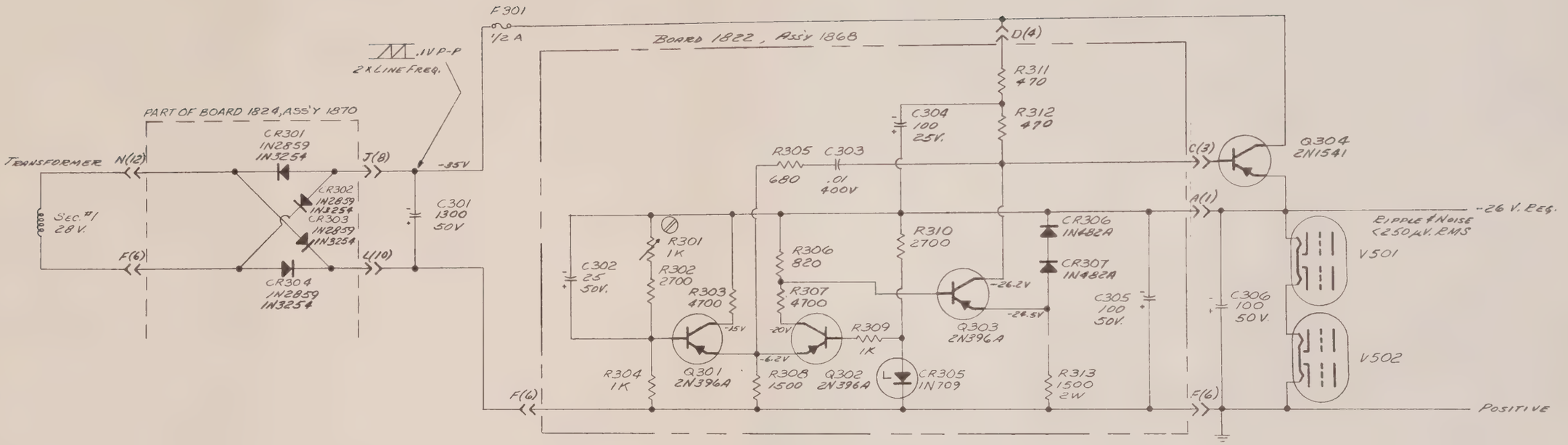
T-3101-J




# SCHEMATIC COLLECTOR SUPPLY

MODEL 310
MODEL 311

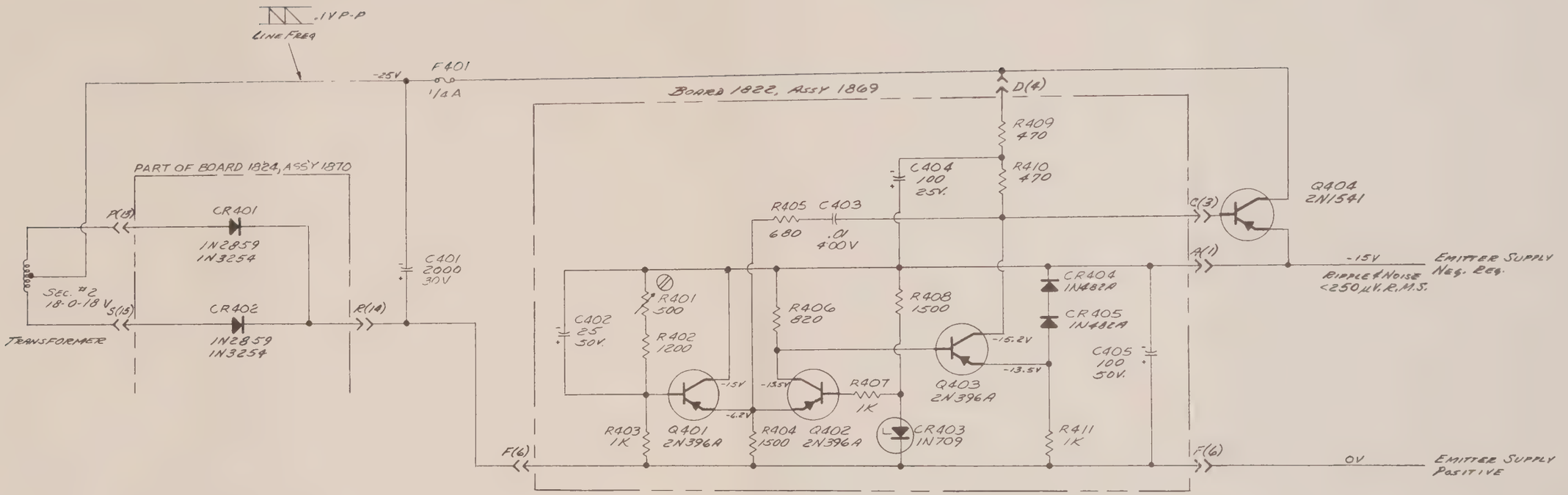
T-3102-J




SCHEMATIC
-26 VOLT SUPPLY

MODEL 310
MODEL 311

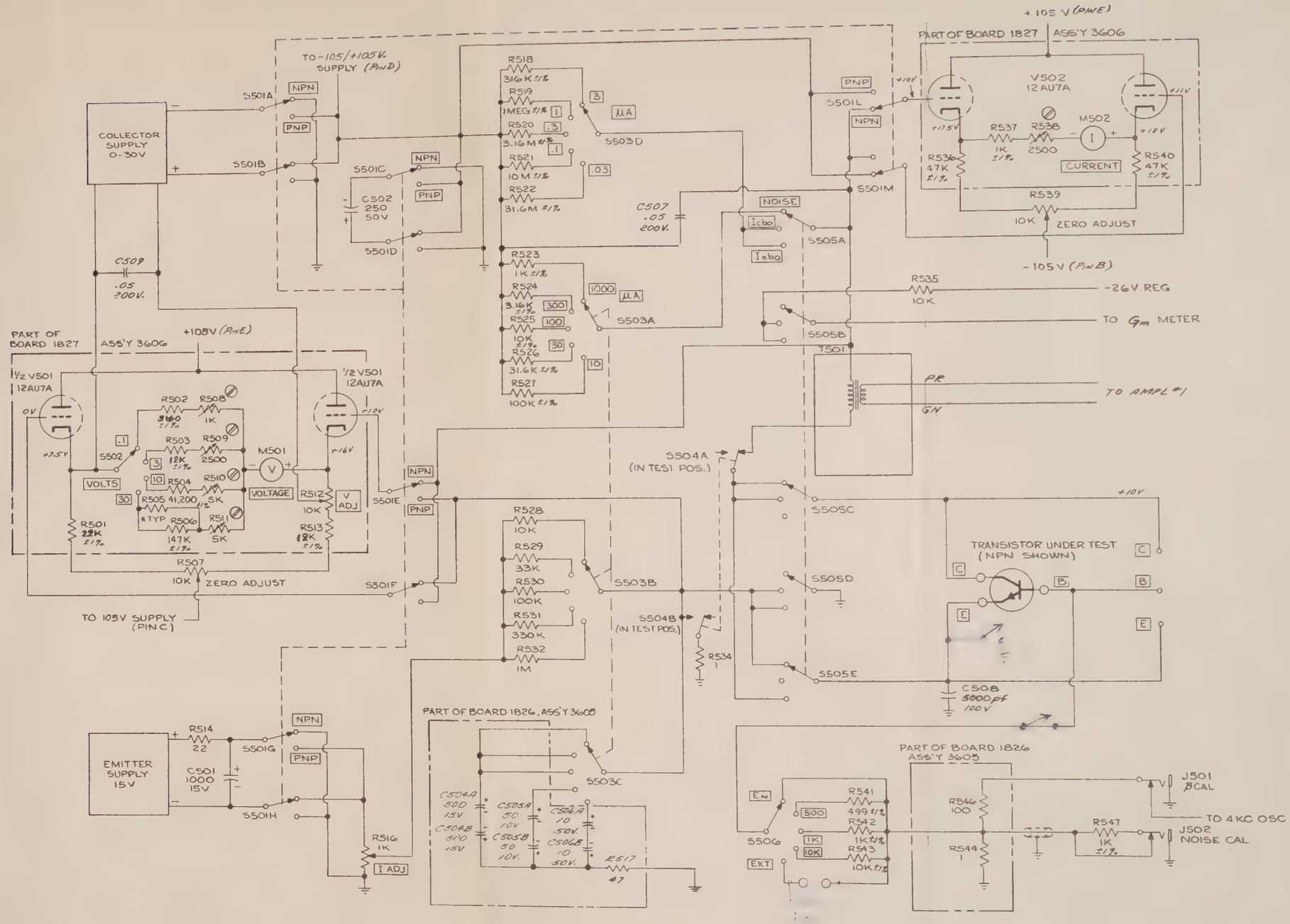
T-3103-H




SCHEMATIC
EMITTER SUPPLY

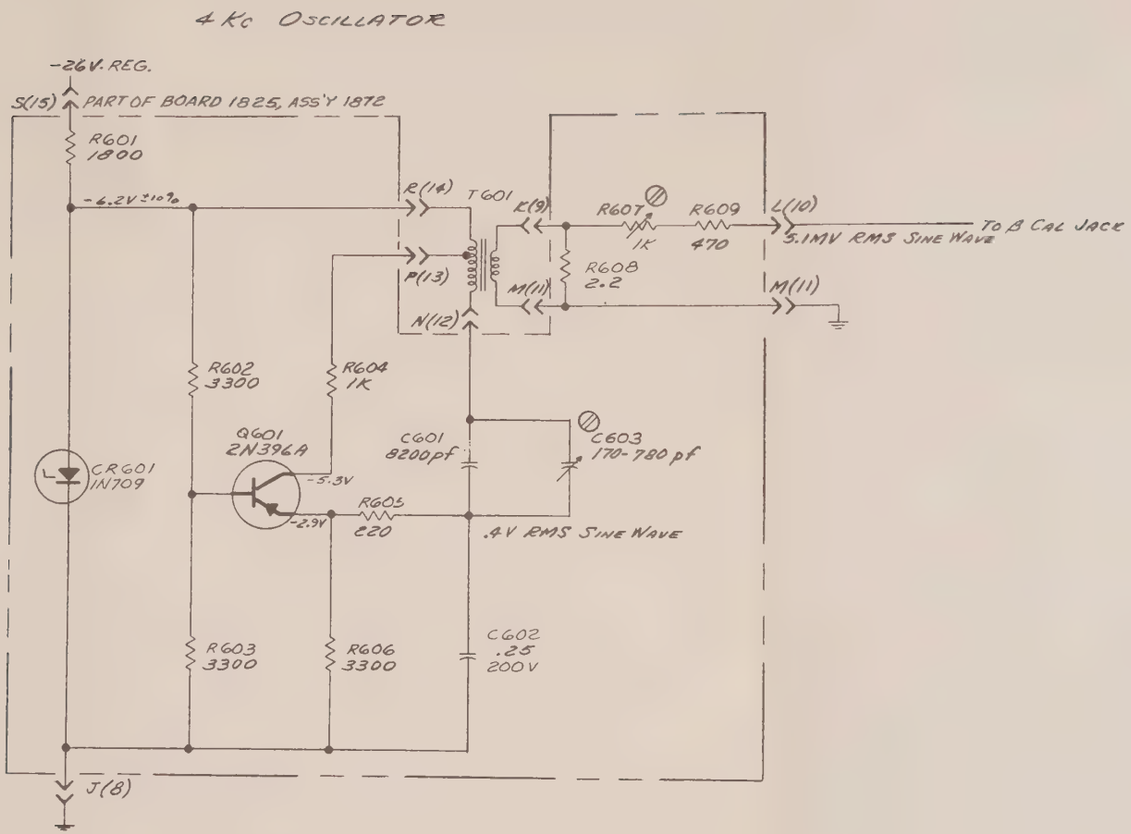
MODEL 310
MODEL 311

T-3104-J



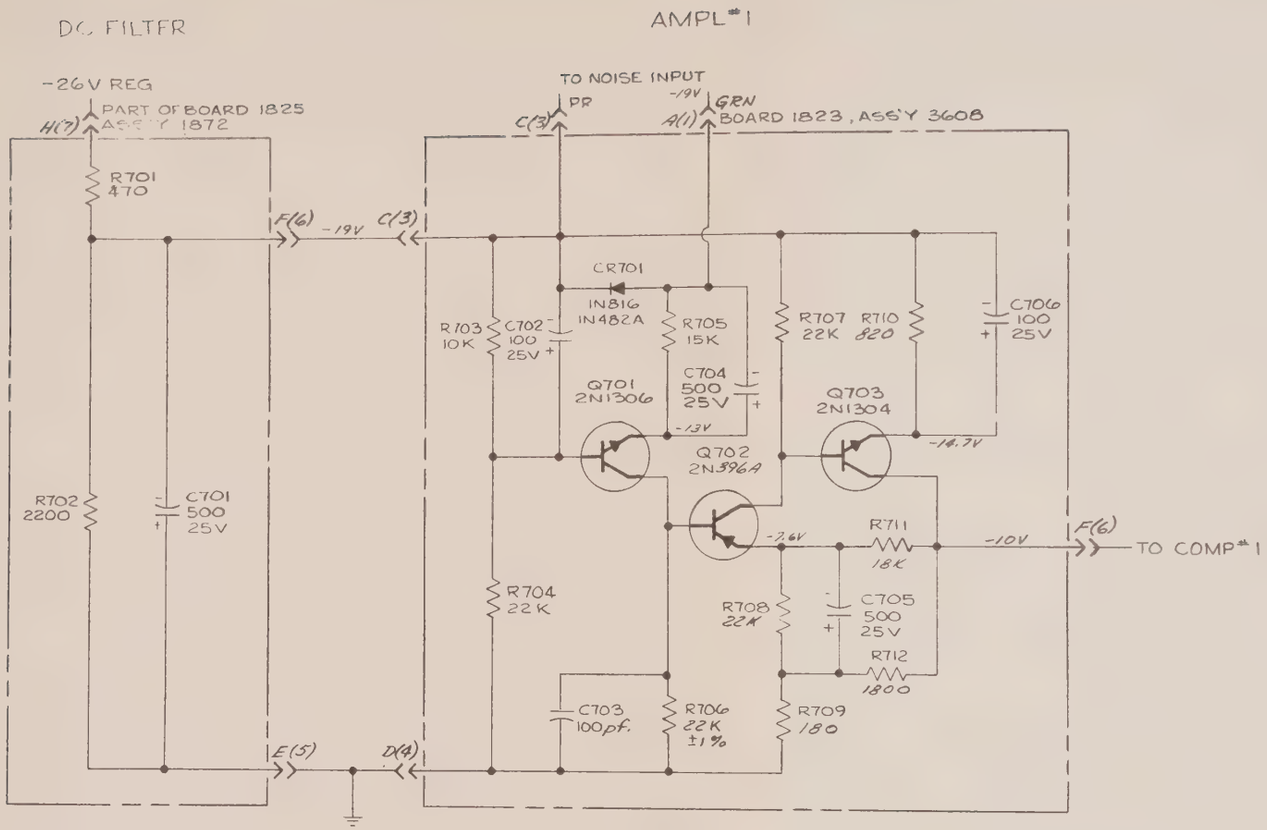

SCHEMATIC
FRONT PANEL SWITCHING
MODEL 311

C-3601-J



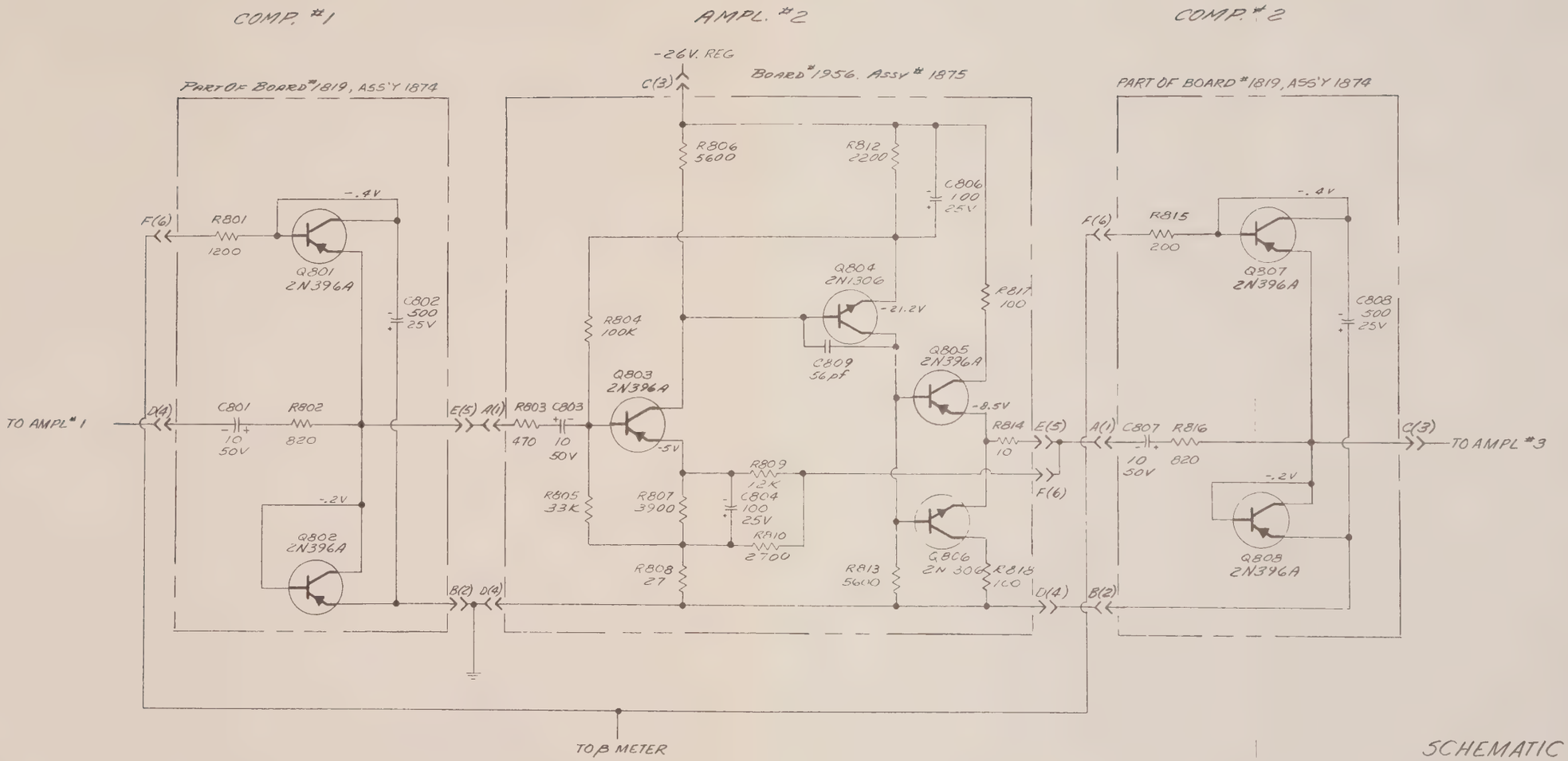

SCHEMATIC
4KC OSCILLATOR
MODEL 310
MODEL 311

T-3106-E




SCHEMATIC
AMPLIFIER #1 & FILTER
MODEL 311

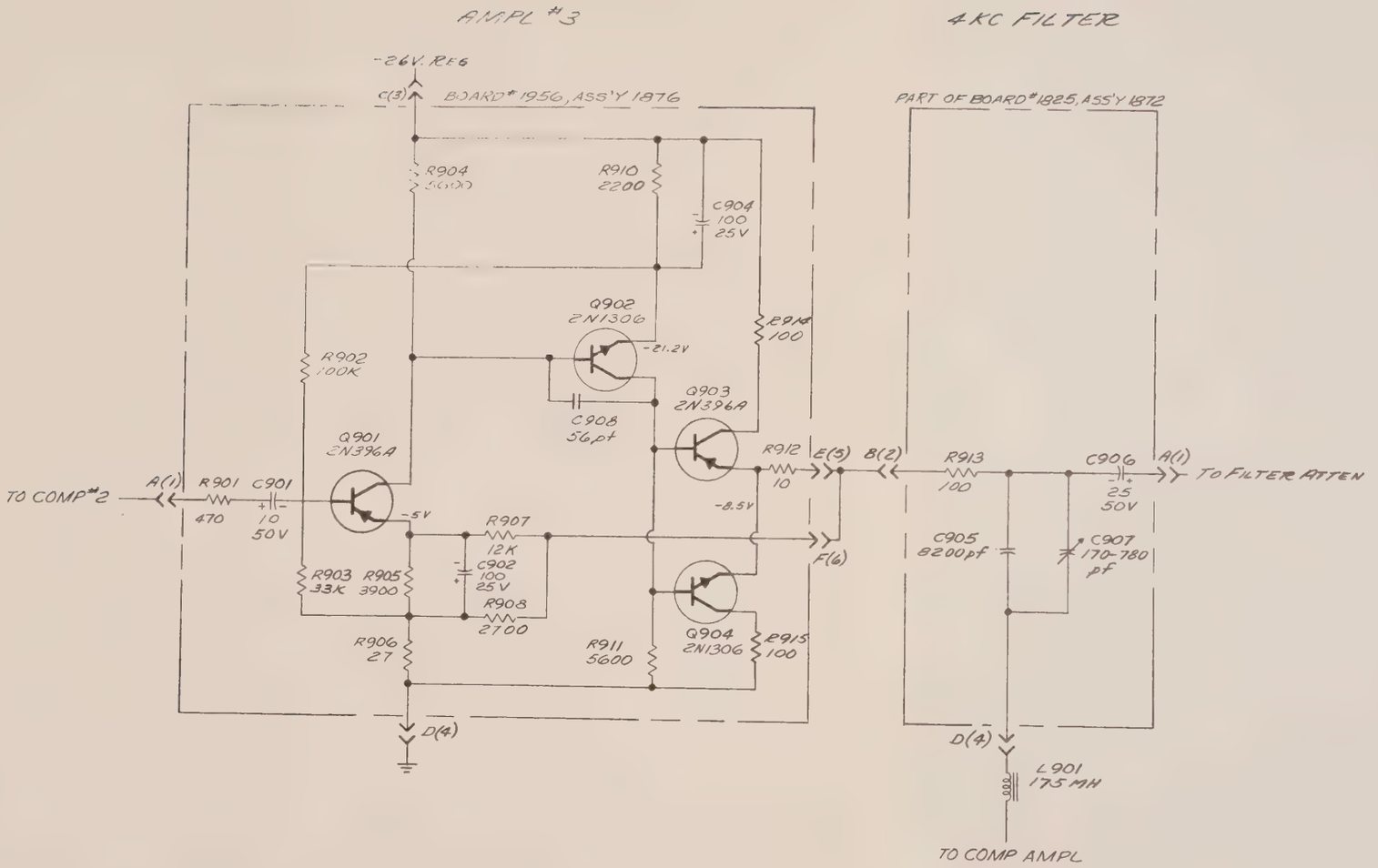
T-3602-F




SCHEMATIC
COMPRESSOR #1 - AMPLIFIER #2 - COMPRESSOR #2

MODEL 310
MODEL 311

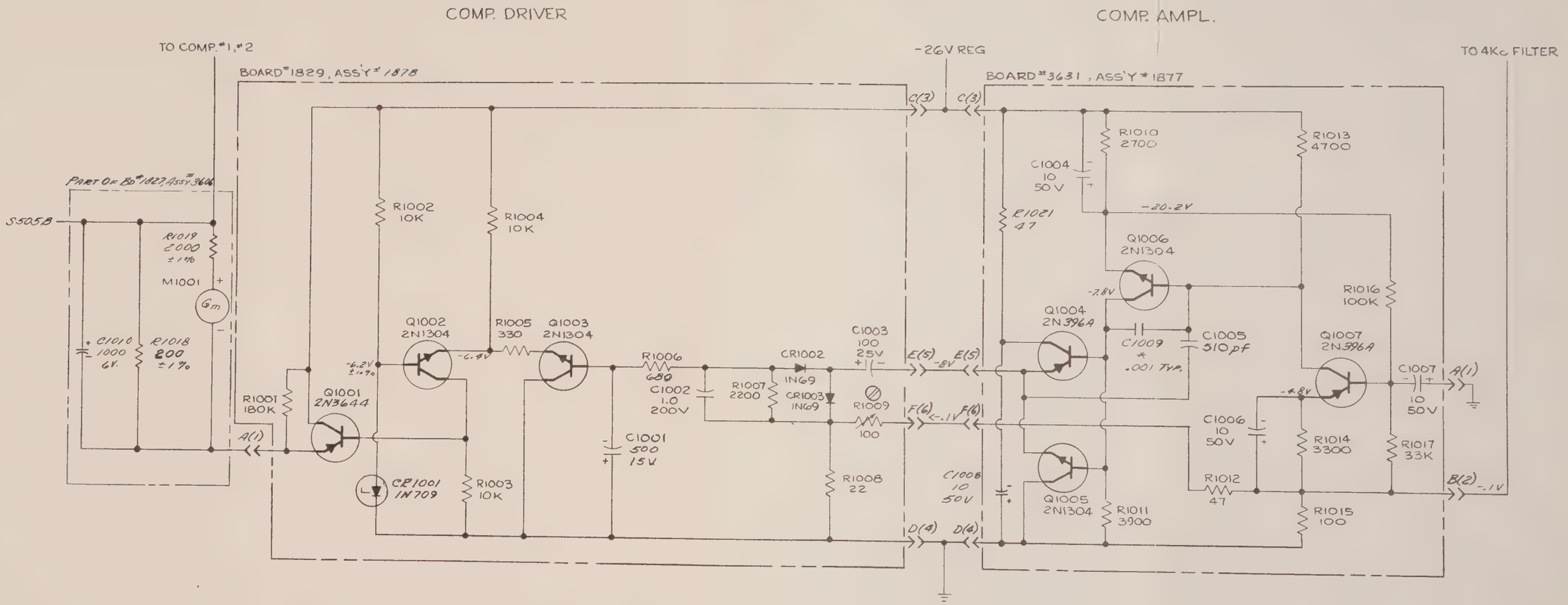
T-3108-H




SCHEMATIC
AMPLIFIER #3 - 4KC FILTER

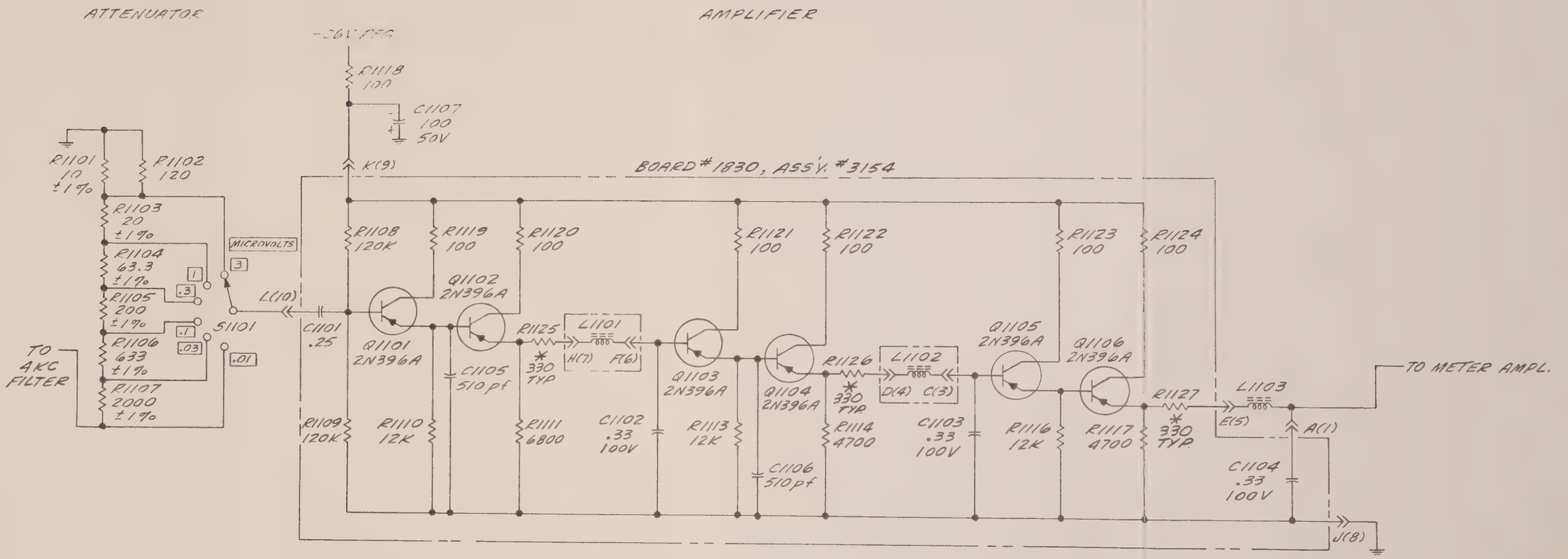
MODEL 310
MODEL 311

T-3109-H



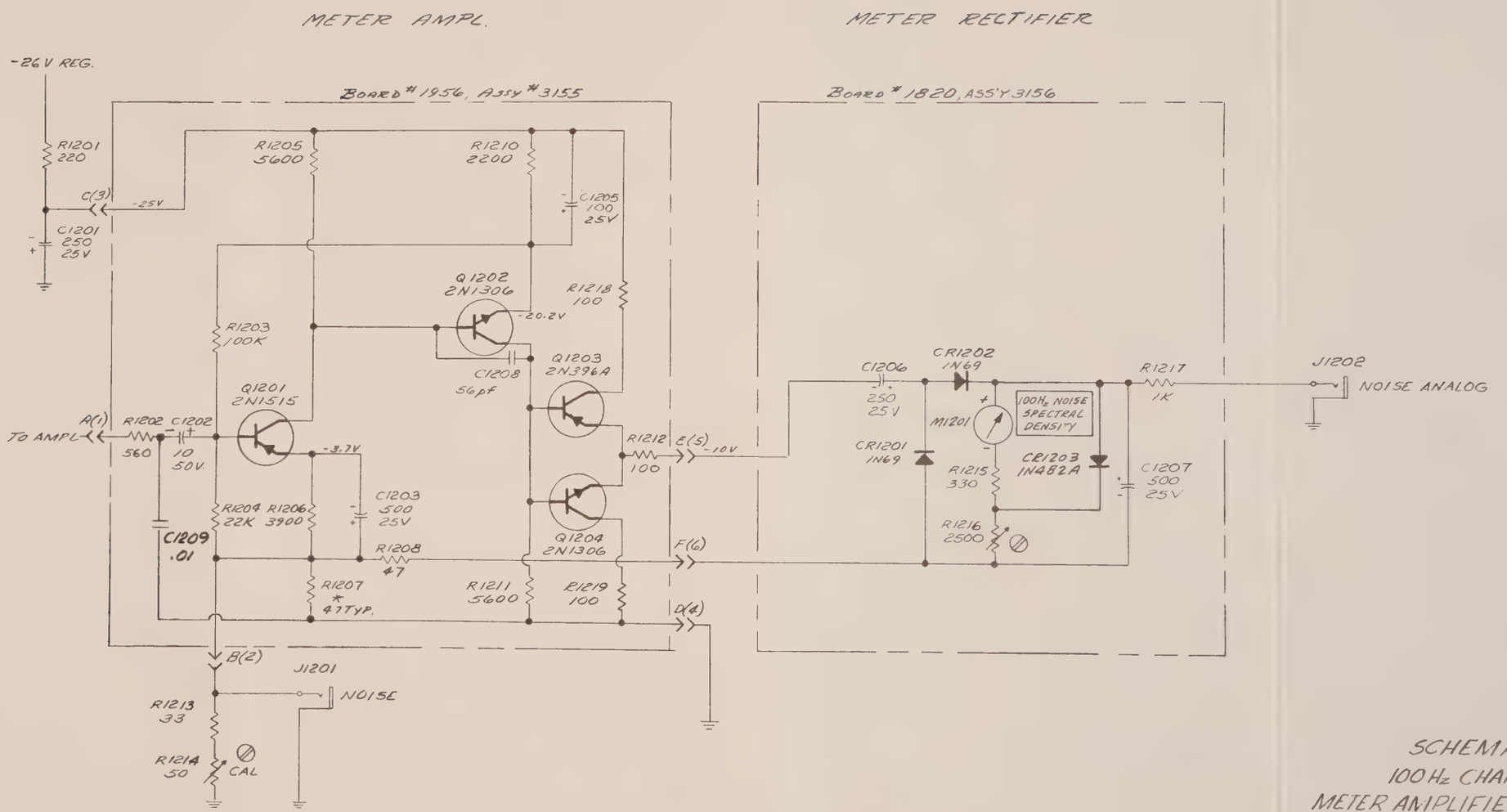

SCHEMATIC
COMPRESSOR AMPLIFIER-
COMPRESSOR DRIVER
MODEL 311

T-3603-K




SCHEMATIC
100 Hz CHANNEL
AMPLIFIER & FILTER
MODEL 310
MODEL 311

T-3111-J

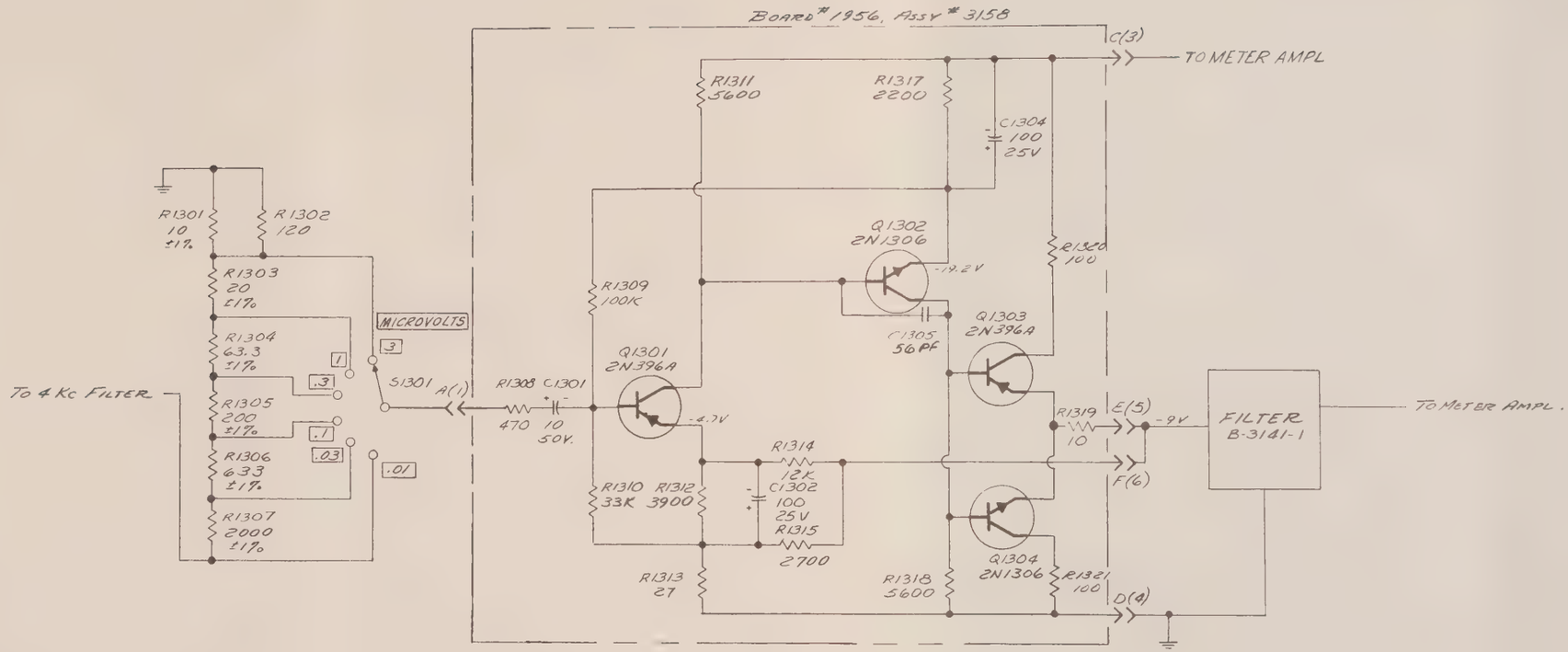



SCHEMATIC
100 Hz CHANNEL
METER AMPLIFIER & RECTIFIER

MODEL 310
MODEL 311

T-3112-L

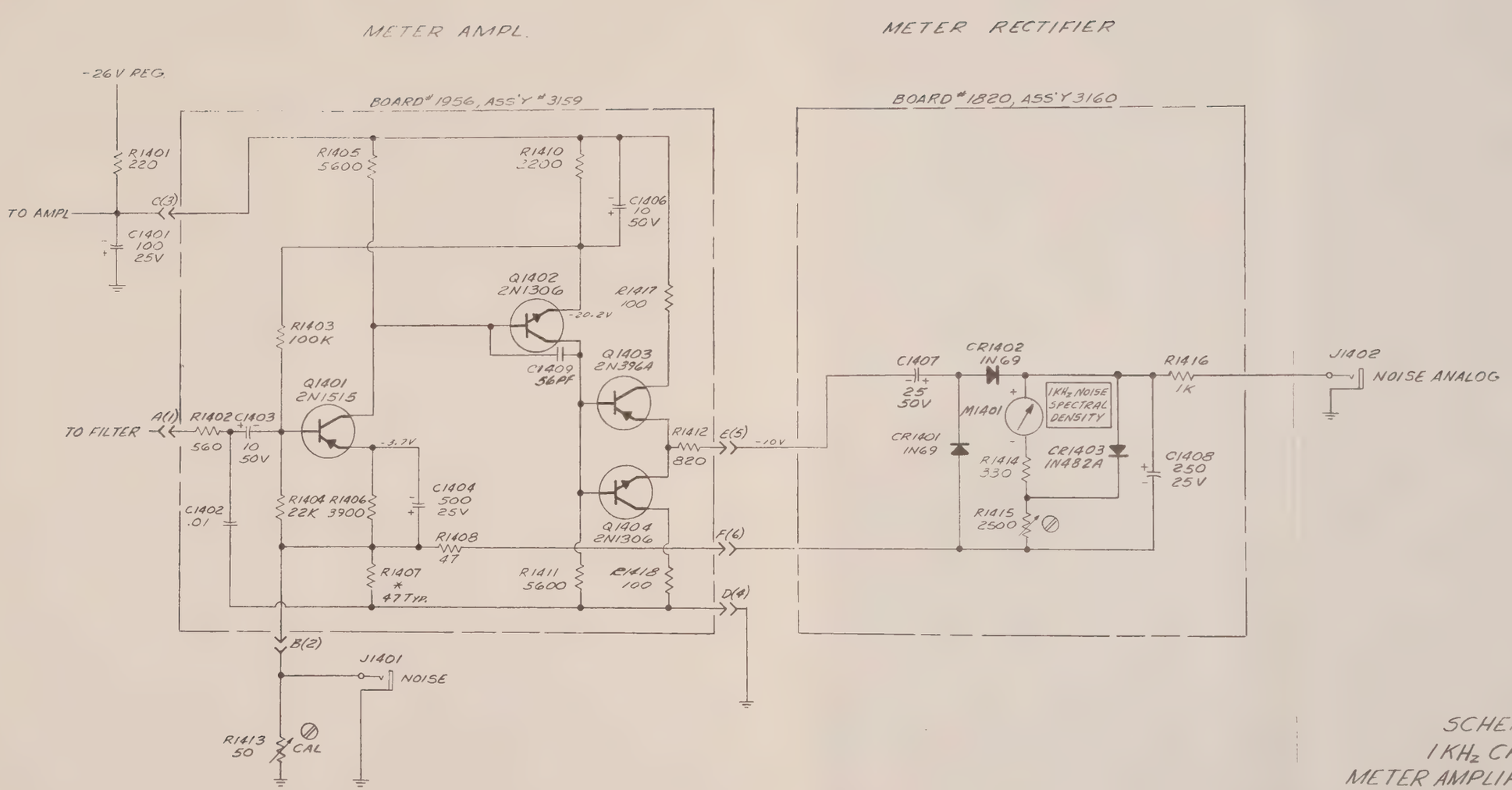
ATTEN. AMPL. FILTER




SCHEMATIC
1 KHz CHANNEL
AMPLIFIER & FILTER

MODEL 310
MODEL 311

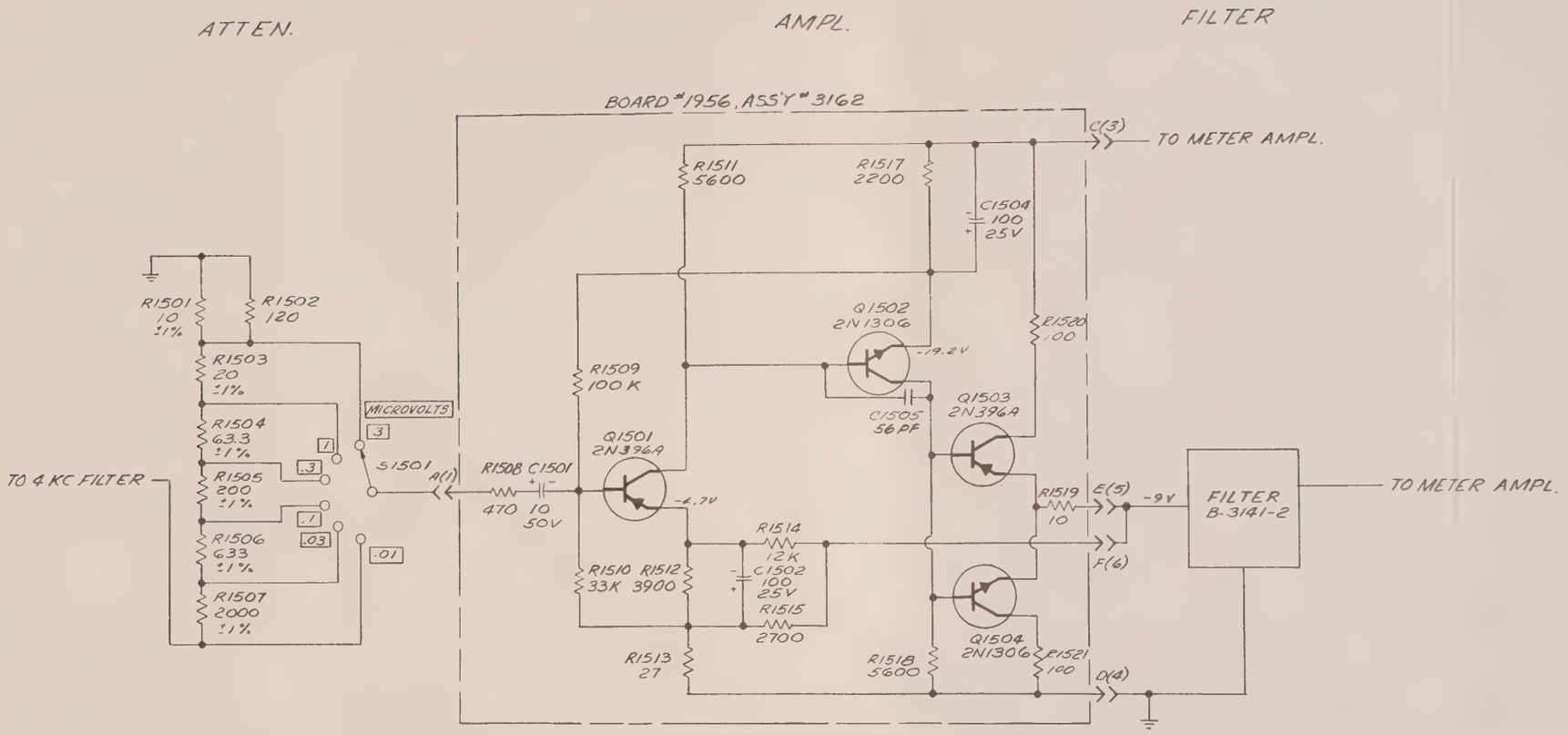
T-3113-H




SCHEMATIC
1 KH$_z$ CHANNEL
METER AMPLIFIER & RECTIFIER

MODEL 310
MODEL 311

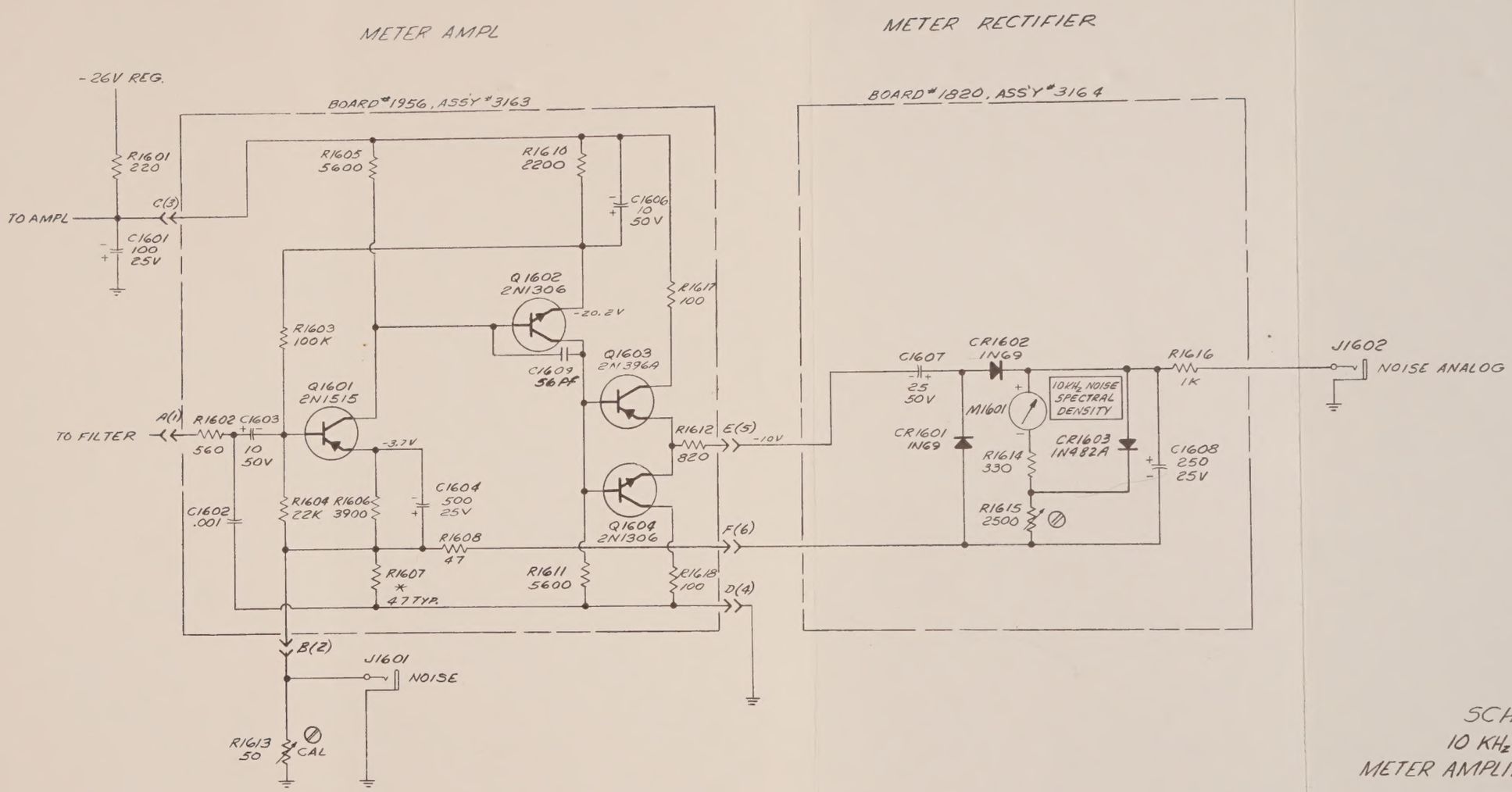
T-3114-J




SCHEMATIC
10 KH$_z$ CHANNEL
AMPLIFIER & FILTER

MODEL 310
MODEL 311

T-3115-H




SCHEMATIC
10 KH$_z$ CHANNEL
METER AMPLIFIER & RECTIFIER

MODEL 310
MODEL 311

T-3116-J